AD-A175 181 CROWLEY ALDEN A-4 OIL SKIMMER OPERATIONAL TEST REPORT 1/1
(U) MASON AND HANGER-SILAS MASON CO INC LEONARDO NJ
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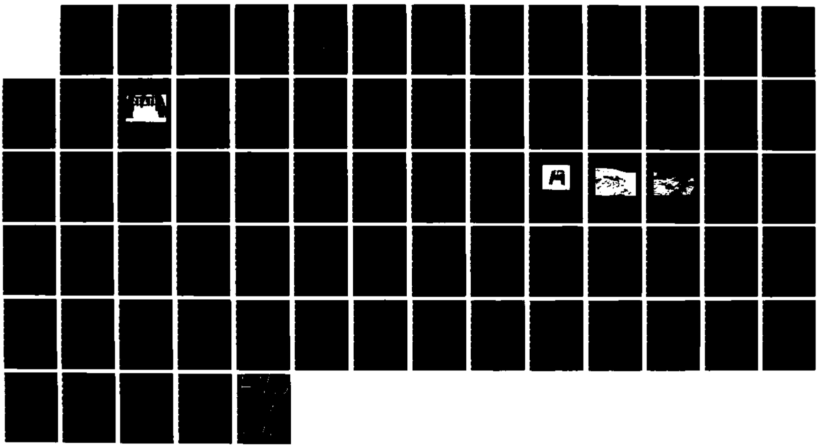
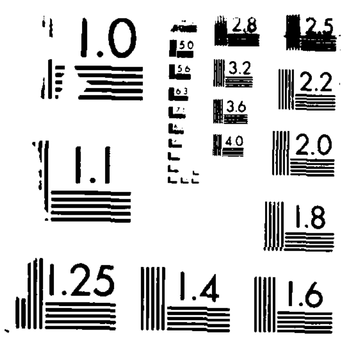




RESOLUTION TEST CHART

(12)

CR-87.003

October 1986

An Investigation Conducted by Mason & Hanger-Silas Mason Co., Inc.
Leonardo NJ

Sponsored by Naval Facilities Engineering Command

NCEL
Contract Report

AD-A175 181

Crowley Alden A-4 Oil Skimmer Operational Test Report

ABSTRACT The Environmental Protection Agency (EPA) tested the Crowley Alden A-4 Oil Skimming System at its Oil and Hazardous Simulated Environmental Test Tank (OHMSETT) facility in Leonardo, NJ. This testing was sponsored by the Naval Civil Engineering Laboratory (NCEL). The tests were required as part of a Navy purchase to assure that the product met or exceeded specifications in an RFP issued in 1985.

During these tests the skimmer recovered 2 to 3 gallons per minute (gpm) [7.5 to 11.4 liters per minute (lpm)] of oil. There was little or no variation in oil recovery rate introduced by altering test conditions. In calm water, the skimmer recovery efficiency was minimally 85 to 95%. Under wave conditions, the recovery efficiency was 65 to 75%.

The test program included measurement of the maximum pump rate of an ancillary double diaphragm pump. The greatest pump rate that should be expected is 70 to 80 lpm (18 to 21 gpm). Lower capacities were measured with added head, but the pump performed equally well with DFM as with water. Overall, the skimmer met or exceeded the performance characteristics required for inner harbor use.

NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME CALIFORNIA 93043

METRIC CONVERSION FACTORS

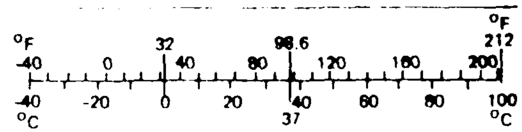
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CR 87 003	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Crowley Alden A-4 Oil Skimmer Operational Test Report		5. TYPE OF REPORT & PERIOD COVERED Final 1 MAY 1986 - 30 JUNE 1986 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Michael Borst		8. CONTRACT OR GRANT NUMBER(s) 68-03-3203
9. PERFORMING ORGANIZATION NAME AND ADDRESS Mason & Hanger-Silas Mason Co, Inc PO Box 117 Leonardo, NJ 07737		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Y0817-004-01-511
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Civil Engineering Laboratory Port Hueneme, CA 93043-5003		12. REPORT DATE October 1986 13. NUMBER OF PAGES 62
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Facilities Engineering Command 200 Stovall Street Alexandria, VA 22332-2300		15. SECURITY CLASS (of this report) 15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

oil skimmer, oil pollution, oil mop, OHMSETT, oil spill, oil recovery, oil spill equipment

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Environmental Protection Agency (EPA) tested the Crowley Alden A-4 Oil Skimming System at its Oil and Hazardous Simulated Environmental Test Tank (OHMSETT) facility in Leonardo, NJ. This testing was sponsored by the Naval Civil Engineering Laboratory (NCEL). The tests were

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DISCLAIMER

Although the research described in this article has been funded wholly by the United States Navy through the United States Environmental Agency under Contract No. 68-03-3203 to Mason & Hanger-Silas Mason Co., Inc., it has not been subjected to the Agency's peer and administrative review and, therefore, does not necessarily reflect the views of the Agency and no official endorsement should be inferred. The mention of trade names or commercial products does not necessarily constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency; the permitting and other responsibilities of State and local governments; and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes tests conducted on the Crowley Alden A-4 Oil Skimmer at OHMSETT in May 1986. The report is presented by Mason & Hanger-Silas Mason Co., Inc. as fulfillment of Contract No. 68-03-3203, Work Assignment 130. It covers the period between May 1, 1986 and June 30,1986. For further information, please contact Richard A. Griffiths at the United States Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory, Raritan Depot, Woodbridge Avenue, Edison, New Jersey, Telephone No. 201-321-6600 Extension 6629.

David Stephan, Director
Hazardous Waste Engineering Research Laboratory

FIGURES

TABLES

TABLES (continued)

SECTION I

INTRODUCTION

Purpose of Tests

The U.S. Naval Civil Engineering Laboratory (NCEL) issued an RFP to the general public in 1985. This RFP was for purchase of stationary oil skimmers specifically intended to recover small spills of light oil. The system selected from the RFP responses was the Crowley Alden A-4. Prior to purchase of the skimmers, the USN sponsored tests at the United States Environmental Protection Agency's (EPA) Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) facility. These tests are designed to document the abilities of the oil collection system in accordance with the RFP. The tests were not conducted to maximize skimmer performance. These tests were run from 19 May to 30 May 1986.

System Description

The Crowley/Alden A-4 oil skimming system is intended to provide a complete package for recovery of small spills of light oil. The system contains five basic units: the skimmer, a transfer pump, an air compressor, a portable storage bladder, and support hoses. The system is marketed by Crowley Environmental Services Corp. of Seattle, Washington.

The skimmer is designed around an aluminum catamaran hull. Each of the hulls is cylindrical, 8 inches (203 mm) in diameter, 60 inches (152 m) long. The cylinders are 24 inches (0.61 m) apart (center to center). There are two endless belts supported between the hulls. Each belt is 4 inches (102 mm) wide. The belts are driven by air/motor-driven squeegee rollers. Oil adheres to the belts and is then squeezed free by the roller/drums. The oil falls into an oil collection pan. The oil is then transferred from the pan by an air-operated double diaphragm pump.

The pump used for oil transfer, which is included as part of the system, is the Sandpiper SA1-A. The Sandpiper pump is pneumatically driven. It is a double diaphragm pump with 1-inch (25-mm) fittings.

The pump may, depending upon conditions at the spill, discharge into a portable storage bladder. The bladder is a polyurethane pillow tank manufactured by Kepner Plastics Fabricators, Inc. of Torrence, CA (Model SCPT300). The bladder has a designed volume of 300 gallons (1.1 m^3).

The wringer/squeegee drive and transfer pump are air-driven. Compressed air for the system is provided by a gasoline engine driven air compressor. The compressor is manufactured by ENERGAIR America, Inc. It is driven by an 8-hp (60 KW) Briggs and Stratton gasoline engine.

Four hoses are provided with the skimming system, two 25-ft (7.6-m) long, 1-inch (25-mm) diameter hoses, and two 25-ft (7.6-m) long $\frac{1}{4}$-inch (6-mm) diameter air hoses.

SECTION 2

CONCLUSIONS

The Crowley Alden A4 oil skimmer collected between 2 to 3 gpm (7.6 and 11.4 liters/min) regardless of test conditions. The recovery efficiency in calm water was in excess of 85% and above 70% in waves.

There were operational difficulties encountered with the double diaphragm pump shipped with the system. A replacement pump was used for part of the testing. There were no operating problems other than those associated with the pump.

The skimmer readily passed floating debris in calm water. When sorbent material was intentionally placed on the collection belts, the wringer/drive was blocked and jammed. It is considered remotely possible that debris will be splashed onto the belts in waves as oil was splashed over the pontoons onto the recovery belts.

Test conducted on the pump prior to recovery tests indicate that, with minimal head, the pump will deliver 20 gpm (76 lpm) when driven by the system compressor.

The recovered fluid storage bladder will contain in excess of 359 gal (1.3 m^3).

SECTION 3

RECOMMENDATIONS

Air Compressor

A pressure regulator should be installed on the air supply line to the air motor to allow control of the belt speed from the compressor. The needle valve at the drive motor is impractical. Regulation of belt speed with the valve will require either retrieving the skimmer or taking a boat to the skimmer. Additionally, the wringer is designed to operate at a maximum air pressure of 80 psig (550 KPa). The compressor initially supplies line pressure in excess of 100 psig (670 KPa). Without regulation, there is a possibility of damage to the air motor.

Storage Bladder

The camlock arrangement, as built does not provide for emptying the bladder. A 1-inch double male camlock should be included for completeness. When air is pumped into the bladder, it rises to the top of the bladder and escapes through the vent. It carries liquid from the bladder with it as it is vented. Positive displacement pumps will routinely pump air if no liquid is available. A baffle plate should be installed within the vent pipe to prevent oil loss through this mechanism.

Operating Manual

The operating manual should include more specific information regarding the skimmer and skimmer operation. It would be useful to the operator to know, for example, that oil spilling from the skimmer pan near the rollers indicates that the pump rate should be increased. Photographs or drawings such as the one shown in Figure 1 would be very helpful.

Oil Skimmer

A spare set of belts should be included in the kit along with instruction on signs of wear (frayed ends, etc.) which indicate that the belts should be changed. During these tests, a check valve was installed on the skimmer discharge pipe.

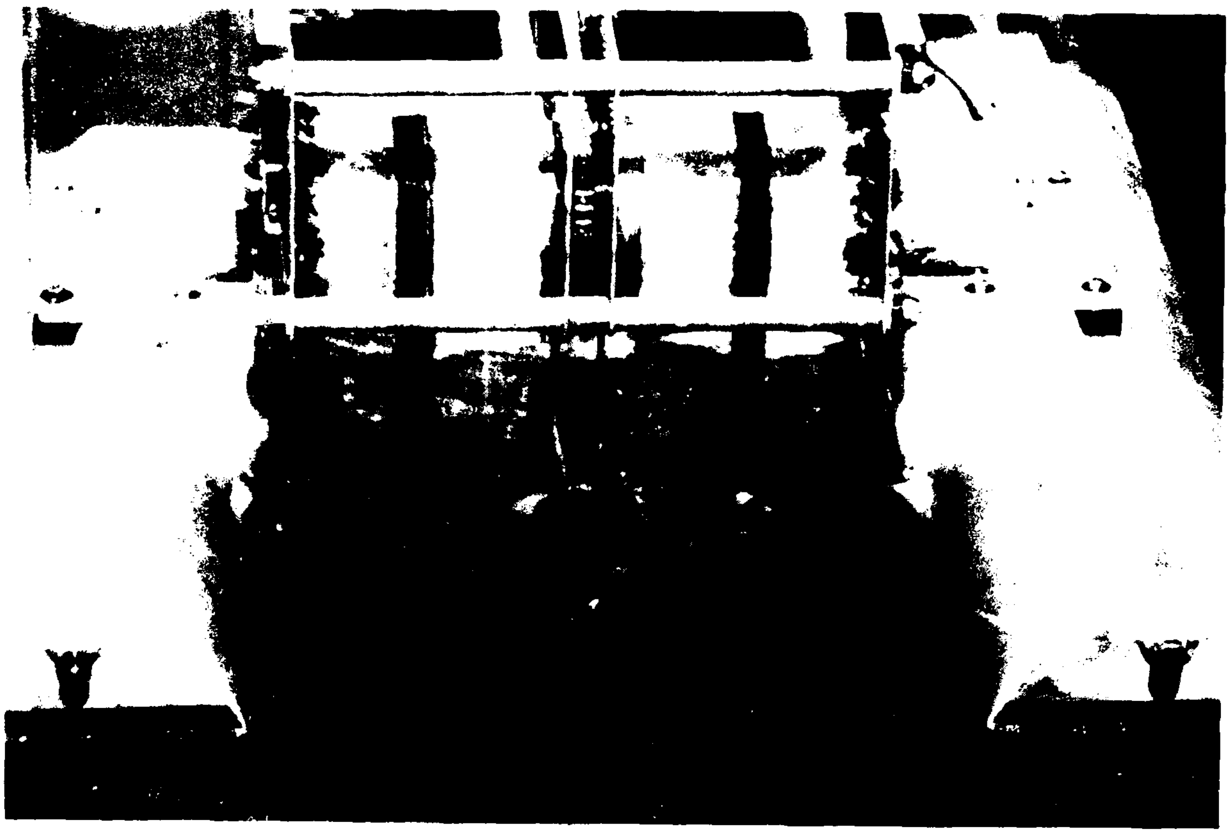


Figure 1. Sample photograph for inclusion in Skimmer Operating Manual. This particular photograph shows an operating condition indicating the the pump rate should be increased.

SECTION 4

PRELIMINARY TESTING

Preliminary tests, not directly associated with oil recovery, were run prior to the oil recovery tests.

MEASUREMENT OF SKIMMER WEIGHT

The skimmer was weighed when received. The dry weight of the skimmer with two belts and no hoses was 106 ± 0.25 lb (48.2 ± 0.6 Kg).

MEASUREMENT OF PUMP CAPACITY

Pump Test Procedures

1. Fill supply barrel with test fluid
2. Sample test fluid
3. Drain any residue from receiving barrel
4. Take initial readings
5. Start compressor
6. Wait for compressor surge tank to reach full pressure
7. Fully open air valve at pump
8. Open supply barrel valve and start stopwatch
9. Measure heights
10. Record time and heights
11. Repeat steps 9 and 10 until fluid supply is depleted.
12. Stop compressor
13. Set up for next test.

Data Reduction

A complete data listing is given in Appendix B. A sample data collection is given in Table 1 along with sample reduction.

Comparison of Water Tests

The recovery barrel height relative to the supply barrel is the only difference between tests in the first and second series. Treating all measurements as independent in each series, there are 50 measurements of the pump rate with the recovery barrel elevated. These tests averaged 18.4 gpm (69.6 lpm) with a standard deviation of 1.50 gpm (5.7 lpm). There are 35 measurements of the pump rate with the barrels at the same level. These results show an average pump rate of 19.1 gpm (72.3 lpm) with a standard deviation of 1.39 gpm (5.3 lpm). The difference in pump rates of 0.7 gpm (2.6 lpm) is significant. Statistical significance is shown using the pooled estimates. From a practical point of view, the 2-m added discharge head reduced performance by 4%.

Comparison of Oil Tests to Water Tests

Pump tests 7 through 9 were run using DFM as the test fluid. These tests yielded an average pump rate of 20.5 gpm (77.6 lpm). These tests were run with a flooded suction and the discharge hose elevated 72 inch (1.83 m). Tests 1 through 3 were run under identical conditions with tap water as the test fluid. These tests yielded an average pump rate of 20.0 gpm (75.7 lpm). The results are statistically equivalent.

The DFM temperature was measured and found to be at either 76 or 66°F (24.4 or 19.4C). The viscosity of the oil at these temperatures is roughly 6 cSt and the specific gravity is roughly 0.84. The properties of the oil make it indistinguishable from water at the test temperatures for pumping purposes.

TABLE 1. SAMPLE PUMP TEST RESULTS

Test Time (min)	Supply Fluid Level Height (inch)	Supply Fluid Drop Rates (inch/min)	Supply Fluid Pump Rates (gal/min)	Receiving Fluid Level Height (inch)	Receiving Fluid Rise Rate (inch/min)	Receiving Fluid Pump Rate (gal/min)
I	II	III	IV	V	VI	VII
0	45.63	-	-	-	-	-
1	42.50	3.13	18.29	0.75	-	-
2	39.00	3.50	20.48	4.25	3.50	21.32
3	35.38	3.63	21.22	7.75	3.50	21.32
4	31.75	3.63	21.22	11.00	3.25	19.79
5	28.38	3.38	19.75	14.50	3.50	21.32
6	24.38	4.00	23.41	17.50	3.00	18.27
7	21.50	2.88	16.83	20.75	3.25	19.79
8	18.00	3.50	20.48	24.00	3.15	19.79
9	14.50	3.50	20.48	27.50	3.50	21.32
10	11.63	2.88	16.83	30.75	3.25	19.79
11	8.00	3.63	21.22	33.75	3.00	18.27
12	4.75	3.25	19.02	37.50	3.75	22.84
13	-	-	-	40.50	3.00	18.27

Average	19.94	20.17
Standard Deviation	1.41	1.41
Number of Observations	12	12
Degrees of Freedom	11	11
t	2.201	2.201
Pump Rate	19.9 ± 1.2 gpm (75.3 ± 4.5)	20.2 ± 0.9 (76.5 ± 3.4)

Column	Description
I	measured time, estimated precision ± 1 sec
II	measured height, estimated precision ±0.25 inch
III	computed rate $R_2 = (H_2 - H_1) / (T_2 - T_1)$
IV	computed pump rate, $P_2 = R_2$ 5.85 gal/inch
V	measured height, estimated precision ± 0.25 inch
VI	computed as III
VII	computed pump rate, $P_2 = R_2$*6.09 gal/inch
Average	Arithmetic Mean
Standard Deviation	N-1 weighted
Pump Rate	Average ± t*standard deviation/$\sqrt{n}$

The results of all pump tests are listed in Table 2.

Observations

When the air compressor completed filling the surge tank, the integral pressure gauge showed approximately 100 psig (289 KPa). After 6 or 7 minutes of operation, the pressure typically fell to 60 to 70 psig (410 to 480 KPa) and remained there for the remainder of the test. Vibration of the gauge needle prevented accurate reading of the pressure.

As the pump operated, variations in pump speed could be heard. There did not appear to be a pattern to the variations.

The fluid withdrawn from the supply barrel occasionally showed a vortex, particularly as the level was diminished. When observed, the supply tank was stirred to eliminate air entrainment while the vortex was present. However, the pump suction was not truly flooded.

Measurement of Fuel Consumption

The outside dimensions of the gasoline tank on the compressor were measured as 4.5" x 9.25" x 2.75" H (114 mm W x 235 mm L x 70 mm H). The height of gasoline in the tank at the start of the compressor was measured and the height was measured again when the compressor was stopped 33:11 later. During that time, the height in the tank dropped 1 3/8 inches (35 mm) . This indicates a fuel consumption rate of 0.45 gal/hr (1.7 lph) and indicates that approximately 1.1 hour running time can be expected. This corresponds well with the observed running time during the tests.

BLADDER CAPACITY

The bladder was placed on a clean concrete slab. The air vent and spigot fittings were installed. One 250-gallon (250C2) barrel was filled with salt water to a height of 44 inches (1.1 m). One length of hose was connected to the bottom spigot of the barrel and the other end to the fill-

TABLE 2. SUMMARY OF PUMP TEST RESULTS

Test No.	Receiving Barrel Pump Rate (gpm)	Supply Barrel Pump Rate (gpm)	Discharge Head[*a] (m)	Suction Lift[*b] (m)	Fluid
1	20.4 ± 1.0 (77.2 ± 3.8)[*d]	-[*c]	1.83	Flooded	Tap Water
2	19.6 ± 0.8 (74.2 ± 3.0)	- -	1.83	Flooded	Tap Water
3	20.2 ± 0.9 (76.5 ± 3.4)	19.9 ± 1.2 (75.3 ± 4.5)	1.83	Flooded	Tap Water
4	19.3 ± 0.7 (73.1 ± 2.6)	18.8 ± 1.1 (71.2 ± 4.2)	3.72	Flooded	Tap Water
5	19.1 ± 1.0 (72.3 ± 3.8)	19.9 ± 0.9 (75.3 ± 3.4)	3.72	Flooded	Tap Water
6	17.4 ± 0.3 (65.9 ± 1.17)	- 0		3.72	0.96 Tank Water
7	20.6 ± 1.3 (78.0 ± 4.9)	19.8 ± 1.2 (74.9 ± 4.5)	3.72	Flooded	DFM @ 76F
8	20.9 ± 0.8 (79.1 ± 3.0)	20.5 ± 0.5 (77.6 ± 1.9)	1.83	Flooded	DFM @ 66F
9	20.5 ± 0.5 (77.6 ± 1.9)	20.6 ± 0.5 (78.0 ± 1.9)	1.83	Flooded	DFM @ 66F

a For the purposes of this report, the discharge hood is considered to the height of the top of the discharge barrel above the pump suction port.

b For purposes of this report, the suction lift is considered to be the height of the suction part above the surface of the supply liquid. "Flooded" indicates that the liquid was above the suction port.

c A dash indicates that the data was not collected.

d Values in parentheses are equivalent pump rates expressed in liter per minute.

ing spigot on the bladder. Both valves were opened and the tank was drained to a water level of 5 inches (127 mm). The 250-gal barrel was refilled to a level of 27.25 inches (692 mm) and drained until water began to constantly flow from the air vent and runover was visible in the vent pipe. The valves were then closed. The height of the water was 2 inches (51 mm). The capacity of the bladder was computed (as shown in Table 3) to be 376 ± 3 gallons (1379 ± 12 liter).

TABLE 3. MEASUREMENTS OF HEIGHT IN WATER SUPPLY BARREL USED TO DETERMINE BLADDER CAPACITY

Starting Height (in)	Finishing Height (in)	Difference (in)	Volume (gal)
44.00 ± 0.13	5.00 1 0.13	39.00 ± 0.25	228.3 ± 1.5
27.25 ± 0.13	2.00 ± 0.13	25.25 ± 0.25	147.8 ± 1.5
Total			376.1 ± 3.0 (1379 ± 12 1)

SKIMMER DRAFT

The skimmer was placed in the tank in calm water. The depth of each of the pontoons was measured fore and aft with a ruler. The skimmer depths without operation are listed in Table 4. In operation, the draft was noted to be as much as 0.75 inches (20 mm) greater than the values listed.

TABLE 4. DRAFT MEASUREMENTS OF INOPERATIVE SKIMMER (INCH)

	Forward		Aft	
	Port	Starboard	Port	Starboard
inch (mm)	3.50 ± 0.25 (89 ± 6)	3.50 ± 0.25 (89 ± 6)	4.50 ± 0.25 (114 ± 6)	4.50 ± 0.25 (114 ± 6)

SECTION 5

OIL RECOVERY TEST

TEST SETUP

A triangular test area was established in the test basin. The boom normally installed under the auxiliary bridge (24-inch Oil Fence) formed the base of the triangle. The east tank wall formed the height of the triangle. The hypotenuse of the triangle was formed by another section of boom (Goodrich Square-D). The base was measured and found to be 29 ft (8.8 m) long. The height was measured and found to be $37\frac{1}{2}$ ft (11.4 m) long. The length of the hypotenuse was used to check that the triangle approximated a true right triangle. The measured length agreed with the computed length to within 1%. The area of the water surface bounded by the booms and tank wall is considered to be 544 ft^2 (50.5 m^2).

The skimmer was placed inside the triangular area. The skimmer was secured using 3/8-inch (7 mm) polypropylene ropes at convenient places around the test triangle. The ropes were tied to the handles on each end of the skimmer pontoons. The compressed air supply hose and pump suction hose were connected to the skimmer from the pump and compressor on the auxiliary bridge. The compressor and pump were 9.5 ft (2.9 m) above the water surface.

Oil was pumped to the test area from the oil farm north of the test area. The oil was pumped from storage using a Viking rotary gear pump through a Tokheim positive displacement meter and approximately 500 ft (152 m) of 2-inch diameter pipe and hose. The end of the hose was fitted with a 1/2-inch ball valve to fine tune the flow rate. A totalizing turbine flow meter (Barton) was installed in the hose run prior to the 1/2-inch valve.

TEST PROCEDURES

An oil slick was established by pumping 67 gallons (253 l) of oil from the storage area onto the water surface within the confines of the triangular area. This volume was determined as to provide a 5-mm slick.

After the slick had been estimated, the air compressor was started. Air pressure was applied to the belt drive motor to start the best movement. Oil feed was then started at 2.5 gpm (9.5 lpm) (nominal) and air was supplied to the recovery pump. Test time was started when fluids were first discharged from the pump into the recovery barrel. The conical bottom barrel was used first to capture recovered fluids. Approximately halfway through the test the discharge hose was transferred to the second barrel, a flat-bottom barrel. At the end of the test, air was removed from the pump and squeegee drive and the oil supply was stopped. Test T4 did not use the triangular test area. Other than this, there was no variation from the procedures.

The belt speed was measured using a marker on the starboard belt three times during a test. This was done by measuring the time required for six complete revolutions of the belt. Belt speed was measured at the start of the test, when the hose was moved from barrel to barrel, and at the end of the test. The time of oil addition was measured, and the total oil volume added. The time of recovery in each recovery barrel was measured.

After the recovery was complete, the depth of fluid in each recovery barrel above a specified datum plane was measured with a ruler and recorded. Bottom spigot valves were opened to allow free standing water to drain. As much free standing water as possible was drained from each barrel. The height of the remaining liquid was measured and samples were taken using stratified sampling thieves. The thieves were carried to the laboratory for determination of water content in the oil-rich phase.

When waves were required for the test, the wave generator was started and allowed to operate for 15 minutes prior to the start of the test. The wave generator operated with a 1.5-inch stroke at 45 rpm. Wave forms were not measured. Historically, these conditions produced harbor chop with a one-third significant wave height of 1.0 ft (0.32 m).

DATA REDUCTION

After each test, the data that was recorded included the parameters listed in Table 5. This data was reduced to obtain the oil recovery rate and recovery efficiency.

Oil Recovery Rate

First the volume of oil in barrel 100C1 was determined using the stripped height calibration function (see Appendix D) and water content as determined at the laboratory.

$$V_{OC} = (2.92*H_{C2} + 5.95)(100 - P_c)/100. \qquad [=] \text{ gallon}$$

Similarly the volume of oil recovered in barrel 100F1 was determined as

$$V_{OF} = (2.60\ H_{F2} - 0.21)(100 - P_F)/100. \qquad [=] \text{ gallon}$$

The total volume of recovered oil V_{OT} was then calculated as

$$V_{OT} = V_{OC} + V_{OF} \qquad [=] \text{ gallon}$$

The oil recovery rate associated with each volume was then calculated. The oil recovery rate in barrel 100C1 was calculated as

$$ORR_C = V_{OC}/t_C. \qquad [=] \text{ gallon}$$

The oil accuracy rate in barrel 100F1 was calculated as

$$ORR_F = V_{OF}/t_F \qquad [=] \text{ gallon}$$

TABLE 5. NOMENCLATURE OF TEST PARAMETERS

Parameter	Unit of Measure	Symbol
Initial height in barrel 100C1	inch	H_{C1}
Stripped height in barrel 100C1	inch	H_{C2}
Initial height in barrel 100F1	inch	H_{F1}
Stripped height in barrel 100F1	inch	H_{F2}
Time of discharge to barrel 100C1	min	t_C
Time of discharge to barrel 100F1	min	t_F
Water content in stripped 100C1	%	P_K
Water content in stripped 100F1	%	P_F

The overall oil recovery rate was calculated as

$$ORR_O = V_{OR}/(t_V + t_C) \qquad [=] \text{ gpm}$$

Recovery Efficiency

Recovery efficiency is defined as the ratio of the volume of oil recovered to the volume of total fluid recovered multiplied by 100

$$RE = 100\ V_O/V_t$$

Like the oil recovery rate, the recovery efficiency was calculated first for the conical bottom barrel, then the flat bottom barrel, and then the overall recovery efficiency. The recovery efficiency in barrel 100C1 was calculated as

$$RE_C = [(2.92\ H_{C2} + 5.95)(100 - P_C)]/[2.92\ H_{C1} + 5.95]. \qquad [=] \%$$

The recovery efficiency in barrel 100F1 was calculated as

$$RE_F = [(2.60\ H_{F2} - 0.21)(100 - P_F)]/(2.60\ H_{F1} - 0.21] \qquad [=] \%$$

Finally, the overall recovery efficiency was calculated as

$$RE_O = [(2.92\ H_{C2} + 5.95)(100 - P_C) + (2.60\ H_{F2} - 0.21)(100 - P_F)]/ \\ [2.92\ H_{C2} + 2.60\ H_{F2} + 5.74] \qquad [=] \%$$

Detailed listings of data can be found in Appendix C.

Test Slick Thicknesses

Slick thickness was calculated for each test based on the test area and an oil material balance. The volume of oil distributed into the test area prior to a given test but after the prior area cleaning was totaled. The recovered oil volumes of the same tests were subtracted to determine the estimate of the volume of oil at the start of the test. This volume was divided by the area bounded by the booms and the wall (assumed to be a right triangle) to determine the slick thickness. The slick thickness at the end of the test was computed by adding the volume of oil distributed during the test to the previous volume and subtracting the volume of oil recovered during the test. This volume was then divided by the area to determine the ending slick thickness.

In order to maintain a slick thickness, the oil recovery rate of the skimmer must be known. This was also one of the parameters to be determined by the tests. The time lag between testing and receiving the lab results being available prohibited accurate balances during the early tests. When the results from the early tests were available, determination of slick thickness was possible. The early tests were run with DFM in calm water. Variation in slick thickness during these tests was comparable. In general the slick was thickening from first to last. Later tests provided much better control of the slick thickness. The test slick thicknesses are listed in Table 6, along with the values use to calculate them.

EXPECTED ERROR IN INDIVIDUAL TEST RESULTS

The expected error in the calculated results is based on measurement errors only. The measurement errors will apply only to the initial and stripped heights in the recovery barrels, pumping time and water content in the sampled fluids. The expected errors are taken as ± 0.25 inch for height

TABLE 6. TEST SLICK THICKNESS SUMMARY

Test No.	Beginning Oil Volume (gal)	Preload Oil Volume Added (gal)	Beginning Oil Volume (gal)	Oil Distribution During Test (gal)	Oil Recovered Test (gal)	Oil Remaining After Test (gal)	Slick Thickness Start (mm)	Slick Thickness End (mm)	Average (mm)
4R	0	70	70	194	124	140	5.2	10.5	7.8
4R1	140	0	140	120	91	169	10.5	12.7	11.4
4R2	0	67	67	126	117	76	5.0	5.7	5.3
8	76	0	76	52	49	79	5.7	5.9	5.8
3	79	0	79	96	83	92	5.9	6.9	6.4
3R	92	0	92	88	65	115	6.9	8.6	7.8
3R1	0	67	67	136	101	102	5.0	7.6	6.3
3R2	102	0	102	124	94	132	7.6	9.9	8.7
4R5	0	67	67	122	106	83	5.0	6.2	5.6
5	0	71	71	113	120	64	5.3	4.8	5.0
5R	0	69	69	117	112	74	5.2	5.5	5.4
5R1	74	0	74	115	119	70	5.5	5.2	5.4
5R2	0	67	67	110	94	83	5.0	6.2	5.6
5R3	83	0	83	119	90	112	6.2	8.4	7.3

measurements and ± 5 seconds for time measurements. The measurement error for water content varies over the range of measurements.

The water content was determined using the procedures outlined in ASTM D-1796. This involves determination of the volume of water in a given sample of measured volume. The JP5 and DFM could not be emulsified to obtain a single sample for analysis even with the addition of chemical emulsifying agents. This forces the analysis to determine the water content in from one to three segments of the collected fluids for each sample taken. The total sample volume and determined water volume were then used to determine the relative water percentage by volume as

$$P = 100\ V_{WT}/V_{ST}$$

where

V_{WT} is the total measured water volume

V_{ST} is the total measured sample volume

and P is the relative water percentage by volume (0-100)

The total water volume, V_W, is the sum of the water volume in each segment of the sample

$$V_{WT} = V_{S1} + V_{S2} + V_{S3}$$

The number of segments varied from one to three depending on total sample volume. In general, there were two segments per sample. Some samples had a single segment and one sample had three segments.

The error in measured total volume is taken as ± 1 ml per segment. The error in measured water volume in each segment is taken as

$$dV_{Wi} = \pm 0.02 \text{ ml} \quad \text{for} \quad 0 < V_{wi} \leq 2$$
$$dV_{Wi} = \pm 0.20 \text{ ml} \quad \text{for} \quad 2 < V_{wi} \leq 5$$
$$dV_{Wi} = \pm 0.30 \text{ ml} \quad \text{for} \quad 5 < V_{wi} \leq 10$$
and
$$dV_{Wi} = \pm 0.50 \text{ ml} \quad \text{for} \quad 10 < V_{wi} \leq 20$$

No segments contained more than 20 ml of water. A summary of all lab analyses is given in Appendix E.

<u>Sample Calculation of Expected Error</u> (Actual Data from Test T3R2)

Measurements Made on the Test Tank

H_{C1} = 20.00 inch
H_{C2} = 14.00 inch
H_{F1} = 23.75 inch
H_{F2} = 20.00 inch
t_C = 23:00 min
t_F = 22:00 min

Measurements Made in Laboratory

Sample	Segment Volume (ml)	Water Volume (ml)
T3R2-C1-1	50 ± 1	0.01 ± 0.02
T3R2-C1-2	24 ± 1	0.50 ± 0.02
T3R2-C2-1	50 ± 1	0.01 ± 0.02
T3R2-C2-2	24 ± 1	0.20 ± 0.02
T3R2-F1-1	50 ± 1	0.01 ± 0.02
T3R2-F1-2	16 ± 1	6.0 ± 0.3
T3R2-F2-1	50 ± 1	0.01 ± 0.02
T3R2-F2-1	20 ± 1	6.0 ± 0.3

Computed Water Content in Samples

Sample ID	Total Volume (ml)	Water Volume (ml)	Relative Water Volume (%)
T3R-C1	74 ± 2	0.50 ± 0.04	0.7 ± 0.1
T3R-C2	74 ± 2	0.20 ± 0.04	0.3 ± 0.1
T3R-F1	66 ± 2	6.0 ± 0.3	9.1 ± 0.7
T3R-F1	70 ± 2	6.0 ± 0.3	8.6 ± 0.7

P_C = 0.5 ± 0.2 % by volume
P_F = 8.9 ± 1.4 % by volume

Fluid Volume Calculations

$$V_{CF} = 2.92(20.00) + 5.95 = 64.4 \pm 0.8 \text{ gallon}$$
$$V_{FF} = 2.60(23.75) - 0.21 = 61.5 \pm 0.7 \text{ gallon}$$
$$F_{OF} = 126 \pm 1.5 \text{ gallon}$$

Oil Volume Calculations

$$V_{CO} = [2.92(14.00) + 5.95][(100-0.5)/100] = 46.6 \pm 0.9 \text{ gallon}$$
$$V_{FO} = [2.60(20.00) - 0.21][(100-8.9)/100] = 47.2 \pm 1.3 \text{ gallon}$$
$$V_{OO} = 93.8 \pm 2.2 \text{ gallon}$$

Fluid Recovery Rates

$$FRR_C = (64.4 \pm 0.8)/(23 \pm 0.1) = 2.8 \pm 0.05 \text{ gpm}$$

$$FRR_F = (61.5 \pm 0.7)/(22 \pm 0.1) = 2.8 \pm 0.04 \text{ gpm}$$

$$FRR_O = (126 \pm 1.5)/(45 \pm 012) = 2.8 \pm 0.05 \text{ gpm}$$

Oil Recovery Rates

$$ORR_C = (46.6 \pm 0.9)/(23 \pm 0.1) = 2.0 \pm 0.05 \text{ gpm}$$

$$ORR_F = (47.2 \pm 1.3)/(22 \pm 0.1) = 2.1 \pm 0.07 \text{ gpm}$$

$$ORR_O = (93.8 \pm 2.2)/(45 \pm 0.2) = 2.1 \pm 0.06 \text{ gpm}$$

Recovery Efficiencies

$$RE_C = 100(46.6 \pm 0.9)/(64.4 \pm 0.8) = 72 \pm 3\%$$

$$RE_F = 100(47.2 \pm 1.3)/(61.5 \pm 0.7) = 77 \pm 3\%$$

$$RE_O = 100(93.9 \pm 2.2)/(125.9 \pm 1.5) = 75 \pm 3\%$$

This procedure was performed for each test. On the basis of this and similar results, the probable error in stated recovery rates (both oil and fluid) is 0.1 gpm. The probable error in recovery efficiency is ± 5% oil.

TEST RESULTS

The skimmer was tested under three conditions: It was first tested in calm water with two oils, DFM and JP5. (The physical properties of the test oils are listed in Appendix E.) The skimmer was also tested with DFM in a 0.32-m harbor chop. A statistical summary of the test results is given in Table 7.

TABLE 7. STATISTICAL RESULTS OF OIL RECOVERY TESTS

Test Oil	Condition	ORR (gpm)	RE (%)	df
DFM	Calm*	2.7 ± 0.4	88 ± 6	3
JP5	Calm	2.4 ± 0.4	93 ± 1	4
DFM	Waves	2.3 ± 0.1	70 ± 8	3
DFM	Waves*1	2.2 ± 0.2	73 ± 4	2

* Excluding Test T4
*1 Excluding Test T3

Calm Water Tests

DFM--

Tests using DFM showed an average recovery efficiency of 88%. The standard deviation was 3.2%. With three degrees of freedom, the 95% confidence level range is estimated as ± 6%. The variation in results is outside the expected error range of any given set of measurements. There does not appear to be a correlation with the estimated slick thickness or belt speed. The inter-test variation is considered to be caused by naturally-occurring discrepancies in uncontrolled independent variables (e.g., time the skimmer spent in wind induced thin slicks, belt age, supply air pressure, etc.). The oil recovery rate averaged 2.7 gpm (10.2 lpm). The standard deviation was 0.3 gpm (1.1 lpm). The 95% confidence level is estimated as 0.4 gpm (1.5 lpm). The variation again exceeds expected error induced from measurement and considered to be caused by the above mentioned sources. In this case, however, there appears to be a relationship with belt speed. The oil recovery rate decreases with increasing belt speed.

JP5--

Tests using JP5 as the test oil showed an average recovery efficiency of 93%. The standard deviation was 0.86%. With four degrees of freedom, the 95% confidence range is 1.1%. This agrees well with the expected error from measurements. The oil recovery rate averaged 2.4 gpm (9.1 lpm) with a standard deviation of 0.28 gpm (1.1 lpm). The 95% confidence range is 0.4 gpm (1.5 lpm).

Wave Tests

Wave tests were only run with DFM as the test oil. These tests showed a decrease in recovery efficiency to an average of 70%. The standard deviation was 4.2%. With three degrees of freedom the 95% confidence range is ± 7%. The variation in test results can partially be attributed to the random effects of wave interaction. Test T3 is a marginal outlier. If it is excluded, the average recovery efficiency was 73% with a standard deviation of 1.4%. The 95% confidence range without T3 is ± 3.5%. The average Oil recovery rate for these tests was 2.3 gpm (8.7 lpm) with a standard deviation of 0.2 gpm (0.8 lpm). The associated 95% level of confidence range is 0.3 gpm (1.1 lpm). Again treating test T3 as an outlier shows an average oil recovery rate of 2.2 gpm (8.3 lpm) with a standard deviation of 0.1 gpm (0.4 lpm). The associated 95% level of confidence range is 02. gpm (0.8 lpm).

The results show an intra-test result as well. The skimmer showed higher performance later in each test. The results are generally not statistically significant. This result is more fully discussed in Appendix C.

Debris Test

In Test T8, the skimmer was operated as in other tests with DFM in calm water. Selected debris was placed near the bow of the skimmer. Two types of debris was selected 1" x 3/4" x 3/4" (25 mm x 19 mm x 19 mm) wood chips and 2" x 12" x 1/4" (51 mm x 305 mm x 6 mm) sorbent (3M Sorbent 100) strips. Both types of debris was readily passed by the skimmer (see Figure 2). When sorbent was placed on top of the skimmer, however, it jammed the roller-squeegee drive mechanism. It could only be freed by manually rolling the drive rollers backwards. The sorbent was readily removed by hand.

This test was not repeated in waves. During wave tests, however, oil was splashed over the skimmer pontoons onto the recovery belts (see Figure 3). It is considered that, if debris had been present, the debris could have landed on the belts and had the same effects.

Actual Versus Desired Results

The Crowley-Alden A-4 oil skimmer met or exceeded 14 of 15 Navy criteria for cleaning up small oil spills. The actual results are compared against the desired values in Table A-1. The only criteria the skimmer did not meet was the wave impact requirement of 80% oil recovery efficiency (ORE) in 1-foot, choppy waves. However, the skimmer just missed the requirement with a 70% ORE, so its performance is acceptable.

TABLE 8. SKIMMER CRITERIA EVALUATION RESULTS

Criteria	Results	
	Desired[a]	Actual
Type of oil	DFM & FP-5	DFM & FP-5
Self-sufficient system	Yes	Yes
Operating manpower	None	None
Recovery rate	120 gph	120 gph
Deployment time	20 min	<20 min
Wave impact	1 ft/80%	1 ft/70%
Proven equipment	Tested	EPA tested
Oil recovery efficiency	80%	65-95%
Portability	1/2-ton truck	1/2-ton truck
Maintainability	Easy	Easy
Set-up manpower	2 people	2 people
Debris impact	None	None
Storage capacity	200 gal	375 gal
Maximum draft	6 in.	5 in.

[a]Reference
J Zimmerle. Proposed Criteria for the Selection of a New Inland Oil Skimmer, Naval Civil Engineering Laboratory, Technical Memorandum M-54-84-08, Port Hueneme, Calif, Jun 1984

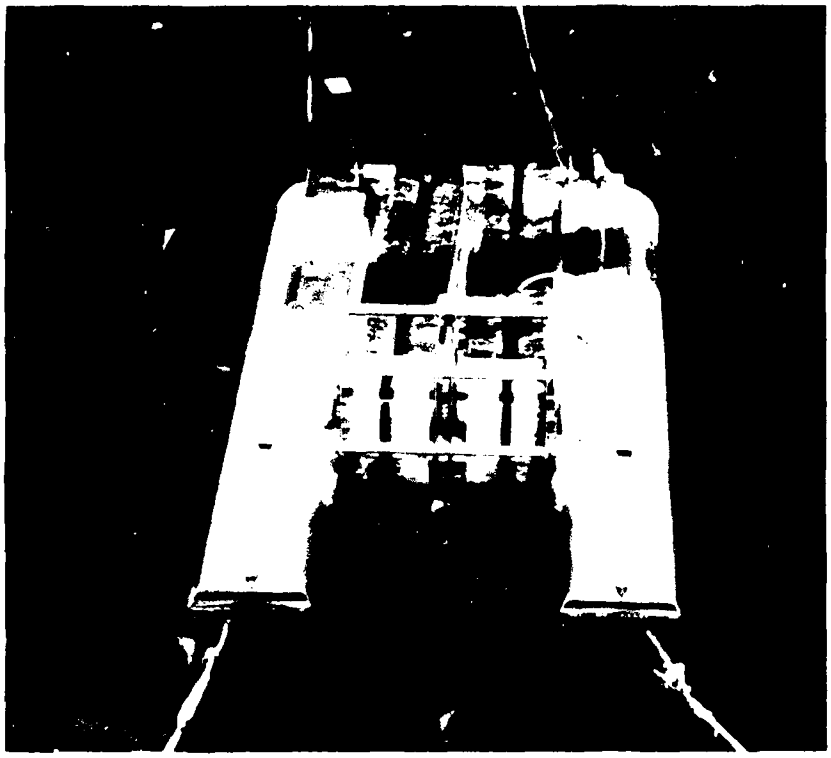


Figure 2. The functional testing included debris tests. This photograph shows wooden blocks floating both in front of the skimmer and immediately behind the skimmer. Debris presented to the skimmer was readily passed without interference with belt operation.

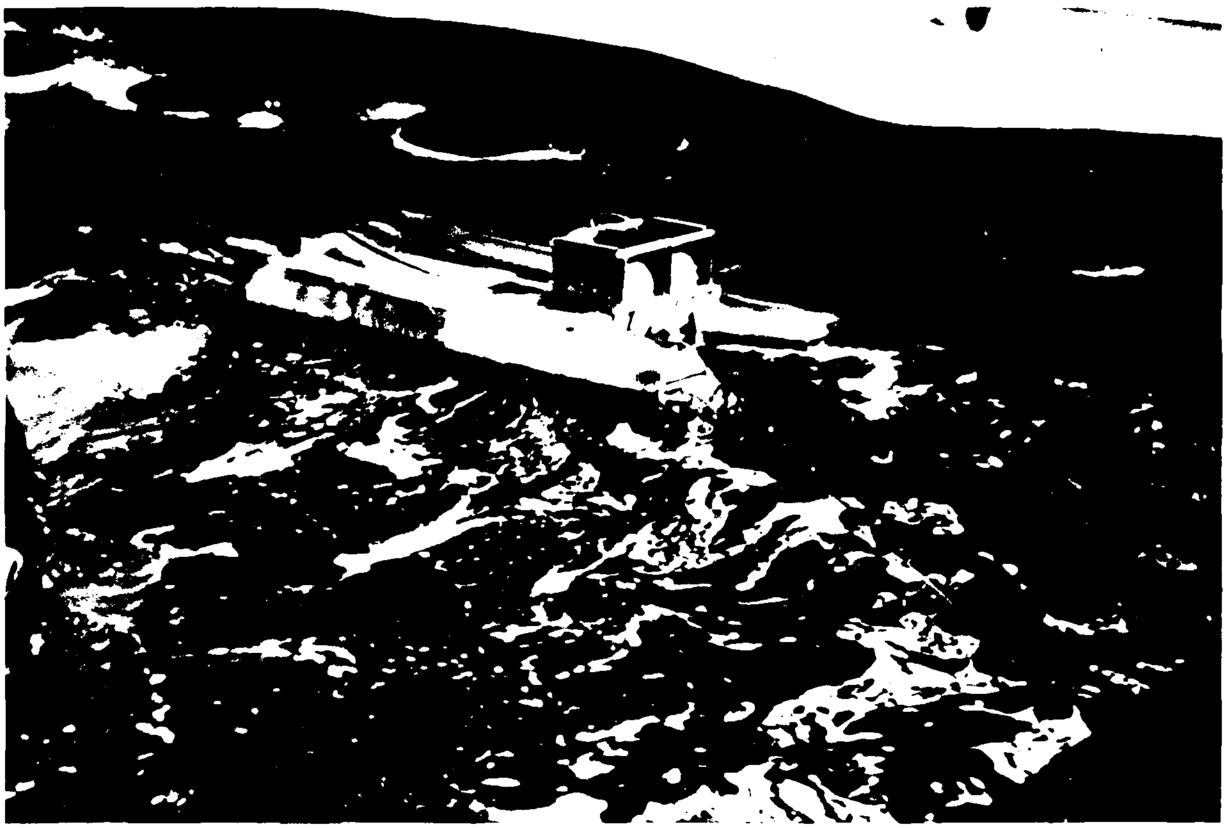
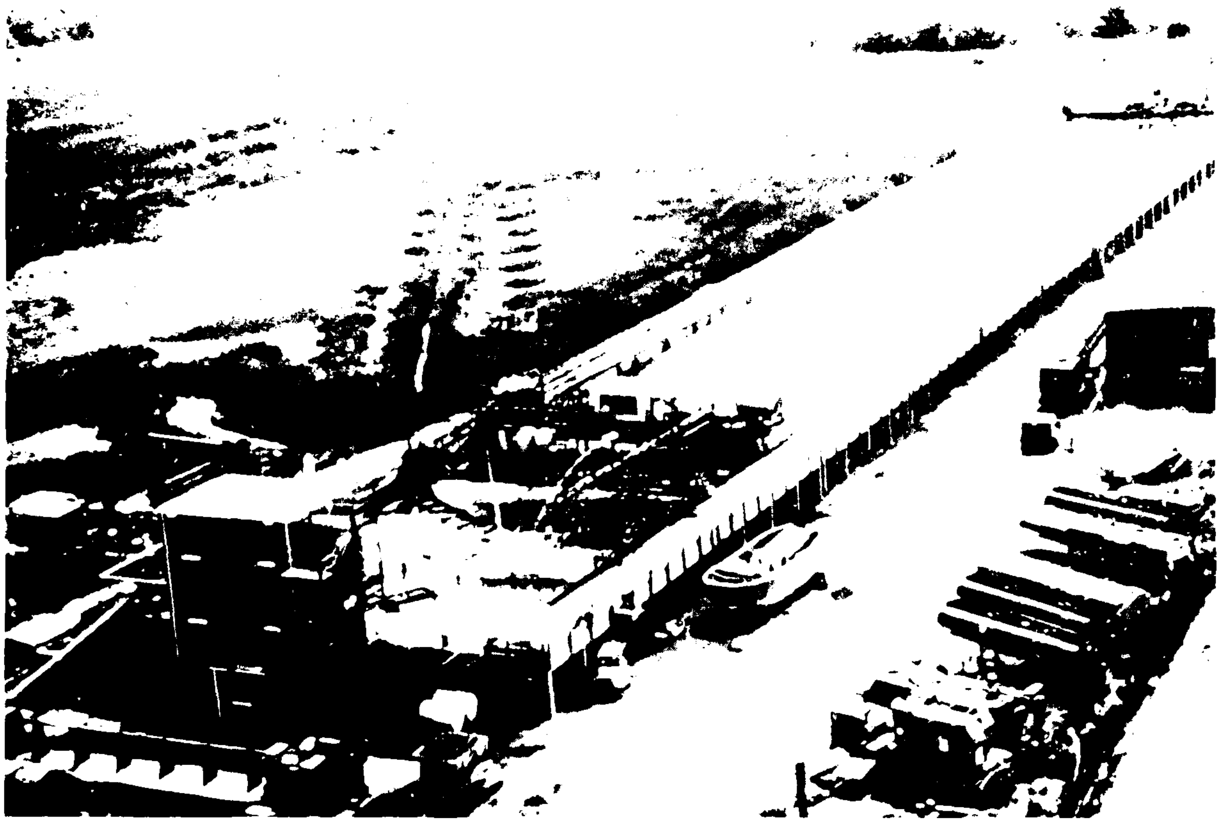


Figure 8. The testing of the skimmer with debris did not include a wave test. In debris-less wave tests, however, oil was frequently splashed over the sides of the skimmer and onto the belt as shown above. It is felt that if debris had been present, it, too, would have been splashed onto the belts.

APPENDIX A
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY



The U.S. Environmental Protection Agency operates the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey. This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control and clean-up of oil and hazardous material spills.

The primary feature of the facility is a pile-supported, concrete tank with a water surface 203 meters long by 20 meters wide and with a water depth of 2.4 meters. The tank can be filled with fresh or salt water. The tank is spanned by a bridge capable of exerting a horizontal force up to 151 kilonewtons while towing floating equipment at speeds to 3.3 meters/second (6.5 knots) for at least 40 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil or hazardous materials on the surface of the water several meters ahead of the device being tested, so that reproducible thicknesses and widths of the test slicks can be achieved with minimum interference by wind.

The principal systems of the tank include a wave generator, a beach, and a filter system. The wave generator and absorber beach can produce regular waves to 0.6 meter high and to 45 meters long, as well as a series of 0.7 meters high reflecting, complex waves meant to simulate the water surface of a harbor. The tank water is clarified by recirculation through a 410 cubic meter/hour diatomaceous earth filter system to permit full use of a sophisticated underwater photography and video imagery system and to remove the hydrocarbons that enter the tank water as a result of testing. The towing bridge has a built-in oil barrier which is used to skim oil to the North end of the tank for cleanup and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume of 9800 cubic meters is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized treatment may be used whenever hazardous materials are used for tests.

Testing at the facility is served from a 650 square meters building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test fluids and tank water are both recycled), a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis. The operating contractor, Mason & Hanger-Silas Mason Co., Inc., provides a permanent staff of twenty multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the area of spill control technology and overall project direction.

For additional information, contact: Richard A. Griffiths, OHMSETT Project Officer, U.S. Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory, Releases Control Branch, Edison, New Jersey 08817. Telephone: 201-321-6629.

APPENDIX B

DETAILED PUMP TEST DATA

TABLE B-1. PUMP TEST 1

Test fluid: tap water
Discharge head: 1.83 m
Suction lift: flooded
Suction barrel: 250C1
Discharge barrel: 250C2

Time (min)	Water Level in Receiving Tank (inch)	Rate of Water Rise (inch/min)	Pump Rate (gpm)
1.5	3.50	-	-
4	11.25	3.10	18.88
6	18.00	3.38	20.56
8	24.75	3.38	20.56
10	31.75	3.50	20.56
12	38.50	3.38	20.56

Average Deviation	20.37
Standard Deviation	0.80
N	5
t	2.776
Pump Rate	20.4 ± 1.0 gpm (77.2 ± 3.8 lpm)

TABLE B-2. PUMP TEST 2

Test fluid: tap water
Discharge head: 1.83 m
Suction lift: flooded
Suction barrel: 250C2
Discharge barrel: 250C1

Time (min)	Water Level in Receiving Tank (inch)	Rate of Water Rise (inch/min)	Pump Rate (gpm)
0	-	-	-
2	4.50	-	-
4	11.50	7.00	20.48
6	18.25	6.75	19.75
8	25.00	6.75	19.75
10	32.00	7.00	20.48
12	38.50	6.50	19.02
14	44.75	6.25	18.29

Average Deviation	20.48 gpm
Standard Deviation	19.75 gpm
N	6
t	2.571
Pump Rate	19.6 ± 0.8 gpm (74.2 ± 3.0 lpm)

TABLE B-3. PUMP TEST 3

Test Fluid: Tap water
Discharge head: 1.83 m
Suction lift: flooded
Suction barrel: 250C1
Discharge Barrel: 250C2

Time (min)	Water Level Height in Receiving Tank (inch)	Rate of Water Level Rise (inch/min)	Pump Rate (gpm)	Water Level in Supply (inch)	Rate of Level Fall (inch/min)	Pump Rate (gpm)
0	-	-	-	45.63	-	-
1	0.75	-	-	42.50	3.13	18.29
2	4.25	3.50	21.32	39.00	3.50	20.48
3	7.75	3.50	21.32	35.38	3.63	21.22
4	11.00	3.25	19.79	31.75	3.63	21.22
5	14.50	3.50	21.32	28.38	3.38	19.75
6	17.50	3.00	18.27	24.38	4.00	23.41
7	20.75	3.25	19.79	21.50	2.88	16.83
8	24.00	3.25	19.79	18.00	3.50	20.48
9	27.50	3.50	21.32	14.50	3.50	20.48
10	30.75	3.25	19.79	11.63	2.88	16.23
11	33.75	3.00	18.27	8.00	3.63	21.22
12	37.50	3.75	22.84	4.75	3.25	19.02
13	40.50	3.00	18.27	-	-	-

Average Deviation	20.17	19.94 gpm
Standard Deviation	1.41	1.84 gpm
N	12	12
t	2.201	2.201
Pump Rate	20.2 ± 0.9 (76.5 ± 3.4 lpm)	19.9 ± 1.2 gpm (75.3 ± 4.5 lpm)

TABLE B-4. PUMP TEST 4

Test fluid: tap water
Discharge head: 3.79 m
Suction lift: flooded
Discharge barrel: 250C1
Suction barrel: 250C2

Elapsed Time (min)	Water Level Receiving Tank (inch)	Rate of of Water Level Rise (inch/min)	Pump Rate (gpm)	Height of Water in Supply (inch)	Rate of Level Fall (inch/min)	Pump Rate (gpm)
0	-	-	-	45.00	-	-
1	-	-	-	41.75	3.25	19.02
2	4.50	-	-	38.00	3.75	21.95
3	7.50	3.00	18.27	34.50	3.50	20.48
4	10.75	3.25	19.79	31.50	3.00	17.56
5	14.00	3.25	19.79	28.50	3.00	17.56
6	17.25	3.25	19.79	25.00	3.50	20.48
7	20.50	3.25	19.79	22.00	3.00	17.56
8	24.00	3.50	21.32	18.50	3.50	20.48
9	27.25	3.25	19.79	15.75	2.75	16.09
10	30.50	3.25	19.79	12.50	3.25	19.02
11	33.75	3.25	19.79	9.50	3.00	17.56
12	36.75	3.00	18.27	6.00	3.50	20.48
13	39.50	2.75	16.75	3.25	2.75	16.09
13.5	41.00	3.00	18.87	-	-	-

Average deviation	19.29	18.79 gpm
Standard deviation	1.13	1.80 gpm
N	12	13
t	2.201	2.179
Pump Rate	19.3 ± 0.7 (73.1 ± 2.6 lpm)	18.8 ± 1.1 gpm (71.2 ± 4.2 lpm)

TABLE B-5. PUMP TEST 5

Test fluid: tap water
Discharge head: 3.76 m
Suction lift: flooded
Discharge barrel: 250C2
Suction barrel: 250C1

Elapsed Time (min)	Water Level Receiving Tank (inch)	Rate of of Water Level Rise (inch/min)	Pump Rate (gpm)	Height of Water in Supply (inch)	Rate of Level Fall (inch/min)	Pump Rate (gpm)
0	-	-	-	45.00	-	-
1	-	-	-	41.25	3.75	21.38
2	4.00	-	-	38.00	3.25	18.53
3	7.75	3.75	21.95	34.50	3.50	19.95
4	11.00	3.25	19.02	31.00	3.50	19.95
5	14.25	3.25	19.02	28.00	3.00	17.10
6	17.50	3.25	19.02	24.50	3.50	19.95
7	20.75	3.25	19.02	21.50	3.00	17.10
8	24.00	3.25	19.05	18.00	3.50	19.95
9	27.50	3.50	20.48	15.00	3.00	17.10
10	30.25	2.75	16.09	12.00	3.00	17.10
11	33.50	3.25	19.02	8.75	3.25	18.53
12	36.25	2.75	16.09	5.50	3.25	18.53
13	39.75	3.50	20.48	2.50	3.00	17.10
13.5	41.50	3.50	20.48	-	-	-

Average Deviation	19.14	19.92 gpm
Standard Deviation	1.63	1.49 gpm
N	12	13
t	2.201	2.179
Pump Rate	19.1 ± 1.0 gpm (72.3 ± 3.8)	19.9 ± 0.9 gpm (75.3 ± 3.4 lpm)

TABLE B-6. PUMP TEST 6

Test fluid: tank water
Discharge head: 3.79 m
Suction lift: 0.96 m
Discharge barrel: 250C2

Time	Water Height (inch)	Water Level Rise Rate (inch/min)	Pump Rate (gal/min)
0	-	-	-
1	-	-	-
2	2.00	-	-
3	5.00	3.00	17.56
4	8.00	3.00	17.56
5	11.25	3.25	19.02
6	14.00	2.75	16.09
7	17.00	3.00	17.56
8	20.00	3.00	17.56
9	23.00	3.00	17.56
10	26.00	3.00	17.56
11	29.00	3.00	17.56
12	32.00	3.00	17.56
13	35.00	3.00	17.56
14	38.00	3.00	17.56
15	41.00	3.00	17.56
16	44.009	3.00	17.56

Average	17.4 gpm
Standard Deviation	0.6 gpm
N	14
t	2.145
Pump Rate	17.4 ± 0.3 gpm (65.9 ± 1.3 lpm)

TABLE B-7. PUMP TEST 7

Test fluid: DFM @ 66 °F
Discharge head: 1.83 m
Suction lift: flooded
Discharge barrel: 250C2
Suction barrel: 250C1

Time (min)	Oil Level (inch)	Oil Fall Rate (in/min)	Pump Rate (gpm)	Oil Level (inch)	Oil Rise Rate (in/min)	Pump Rate (gpm)
0	43.50	-	-	-	-	-
1	39.50	4.00	24.36	0.50	-	-
2	36.00	3.50	21.32	4.75	4.25	24.87
3	32.25	3.75	22.84	7.50	2.75	16.09
4	28.75	3.50	21.32	11.00	3.50	20.48
5	25.50	3.25	19.79	14.25	3.25	19.02
6	22.25	3.25	19.79	17.75	3.50	20.48
7	18.75	3.50	21.32	21.00	3.25	19.02
8	15.50	3.25	19.79	24.50	3.50	20.48
9	12.50	3.00	18.27	27.75	3.25	19.02
10	9.00	3.50	21.32	31.00	3.25	19.02
11	6.25	2.75	16.75	34.50	3.50	20.48
12	-	-	-	37.75	3.25	19.02
13	-	-	-	41.00	3.25	19.02

Average	20.62	19.75 gpm
Standard Deviation	1.99	1.94 gpm
N	11	12
t	2.23	2.20
Pump rate	20.6 ± 1.3 gpm (78.0 ± 4.9)	19.8 ± 1.2 gpm (74.9 ± 4.5 lpm)

TABLE B-8. PUMP TEST 8

Test fluid: DFM @ 66 °F
Discharge head: 1.83 m
Suction lift: flooded
Discharge barrel: 250C2
Supply barrel: 250C1

Time (min)	Oil Level (inch)	Oil Fall Rate (in/min)	Pump Rate (gpm)	Oil Level (inch)	Oil Rise Rate (in/min)	Pump Rate (gpm)
0	42.75	-	-	-	-	-
1	39.25	3.50	21.32	1.00	-	-
2	35.75	3.50	21.32	4.50	3.50	20.48
3	32	3.75	22.84	8.25	3.75	21.95
4	28.5	3.50	21.32	11.75	3.50	20.48
5	25.25	3.25	19.79	15.25	3.50	20.48
6	21.5	3.75	22.84	18.75	3.50	20.48
7	18.25	3.25	19.79	22.25	3.50	20.48
8	14.75	3.50	21.32	25.75	3.50	20.48
9	11.5	3.25	19.79	29.25	3.50	20.48
10	8.25	3.25	19.79	32.75	3.50	20.48
11	5	3.25	19.79	36.00	3.25	19.02

Average	20.90	20.48 gpm
Standard Deviation	1.14	0.65 gpm
N	11	10
t	2.228	2.262
Pump rate	20.9± 0.8 (79.1 ± 3.0)	20.5 ± 0.5 gpm (77.6 ± 1.9 lpm)

TABLE B-9 PUMP TEST 9

Test fluid: DFM @ 66°F
Discharge head: 1.83 m
Suction lift: flooded
Discharge barrel: 250C1
Supply barrel: 250 C2

Time (min)	Oil Level (inch)	Oil Fall Rate (in/min)	Pump Rate (gpm)	Oil Level (inch)	Oil Rise Rate (in/min)	Pump Rate (gpm)
0	44.25	-	-	-	-	-
1	40.50	3.75	21.95	-	-	-
2	36.75	3.75	21.95	4.25	-	-
3	33.25	3.50	20.48	7.75	3.50	21.32
4	29.75	3.50	20.48	11.00	3.25	19.79
5	26.25	3.50	20.48	14.50	3.50	21.32
6	22.75	3.50	20.48	17.75	3.25	19.79
7	19.50	3.25	19.02	21.25	3.50	21.32
8	16.00	3.50	20.48	24.50	3.25	19.75
9	12.50	3.50	20.48	28.00	3.50	21.32
10	9.13	3.38	19.75	31.25	3.25	19.79
11	5.75	3.38	19.75	34.75	3.50	21.32
12	2.25	3.50	20.48	38.00	3.25	19.79
13	-	-	-	41.50	3.50	21.32

Average	20.48	20.62 gpm
Standard Deviation	0.79	0.76 gpm
N	12	11
t	2.201	2.228
Pump rate	20.5 ± 0.5 (77.6 ± 1.9)	20.6 ± 0.5 gpm (78.0 ± 1.9 lpm)

APPENDIX C

DETAILED SUMMARY OF OIL RECOVERY TESTS

The data collected in the oil recovery tests and the values for oil recovery rate and recovery efficiency calculated therefrom is listed in Tables C-1 through C-3. Table C-1 lists the data collected from barrel 100C1. Table C-2 lists the data collected from barrel 100F1. The overall results are listed in Table C-3.

The overall results are listed in the main body of the report. It is worth noting, however, that the results of the second barrel used are higher than the results obtained from the first barrel. This is most obvious in the shorter tests. For example, Test T4R1 showed an oil recovery rate of 2.7 gpm (10.2 lpm) and a recovery efficiency of 74% in the first barrel used, 100C1. The second half of that test showed an oil recovery rate of 3.4 gpm (12.9 lpm) and essentially pure oil was collected.

The difference is less noticeable in longer tests. For example, in Test T4R2 the oil recovery rate in the first barrel was 2.3 gpm (8.7 lpm) with an oil recovery efficiency of 88%. The second half of that test showed an oil recovery rate of 2.9 gpm (11.0 lpm) with a recovery efficiency of 92%.

This may be caused by a time lag for the skimmer to come to steady state operations. The effect of lower performance at the start of the test is diluted in the longer tests by the addition of steady state operation recovery in the first barrel. Table C-4 shows the differences in statistical results.

Effect of Belt Speed

The effect of belt speed can only be extracted from the tests using DFM as the test oil and conducted in calm water, tests T4R, T4R1, T4R2, and T4R5. There does not appear to be any trend in recovery efficiency. There does, however, appear to be a trend in the oil recovery rate (see Figure C-1).

TABLE C-1. RAW DATA AND CALCULATED RESULTS FROM CONICAL BOTTOM BARREL

Test No.	Date	Pump	Oil Used	Waves	Belt Speed (rpm)	Pump Time (min)	Initial Height (inch)	Stripped Height (inch)	Water Content (%)	Total Volume (gal)	Oil Volume (gal)	Fluid Rec. Rate (gpm)	Oil Rec. Rate (gpm)	Rec. Efficiency (%)
T4	5/27	B	DFM	N	NA	22.00	25.50	21.00	16.3	80.4	56.5	3.66	2.56	70.0
T4R*	5/27	B	DFM	N	6	21.98	22.00	20.50	1.8	70.2	64.6	3.9	2.94	92.1
T4R1	5/27	B	DFM	N	6	15.00	16.25	15.00	20.1	53.4	39.7	3.56	2.65	74.4
T4R2	5/28	B	DFM	N	8	23.50	19.00	16.50	0.2	61.4	54.0	2.61	2.30	87.9
T4R5	5/29	S	DFM	N	11	22.03	18.50	13.88	0.2	60.0	46.4	2.72	2.11	77.3
T8	5/28	B	DFM	N	NA	NA	14.75	13.88	7.9	49.0	42.8	NA	NA	87.3
T3**	5/28	S	DFM	Y	11	22.00	29.38	19.50	13.0	91.7	54.7	4.17	2.49	59.5
T3R	5/28	B	DFM	Y	7	15.00	10.00	6.25	15.3	35.2	20.5	2.34	1.37	58.3
T3R1	5/29	S	DFM	Y	11	22.00	21.25	13.75	0.1	68.0	46.0	3.09	2.09	67.7
T3R2	5/29	S	DFM	Y	10	23.00	20.00	14.00	0.5	64.4	46.0	2.80	2.03	72.4
T5	5/29	S	DFM	N	11	22.00	21.00	18.88	0.2	67.3	61.0	3.06	2.77	90.6
T5R	5/30	S	JP5	N	11	22.00	15.88	13.88	0.1	52.3	46.4	2.38	2.11	88.8
T5R1	5/30	S	JP5	N	11	22.00	19.50	17.88	3.7	62.9	56.0	2.86	2.55	89.0
T5R2	5/30	S	JP5	N	11	22.00	13.50	11.75	0.0*1	45.4	40.3	2.06	1.83	88.7
T5R3	5/30	S	JP5	N	11	22.00	15.00	13.63	2.2	49.8	44.8	2.26	2.04	90.1

* Barrel 100F1 used first
** Compressor stalled
*1 Less than 0.05% water by volume
NA Data not available or necessary data to compute the item is not available
Pumps: B = Pump shipped with system, S = Replacement pump

TABLE C-2. RAW DATA AND CALCULATED RESULTS FROM FLAT BOTTOM BARREL

Test No.	Date	Pump	Oil Used	Waves	Belt Speed (rpm)	Pump Time (min)	Initial Height (inch)	Stripped Height (inch)	Water Content (%)	Total Volume (gal)	Oil Volume (gal)	Fluid Rec. Rate (gpm)	Oil Rec. Rate (gpm)	Rec. Efficiency (%)
T4	5/27	B	DFM	N	NA	23.00	30.00	28.00	8.9	77.8	66.1	3.38	2.87	85.0
T4R*	5/27	B	DFM	N	6	23.02	25.00	25.00	8.4	64.8	59.3	2.81	2.58	91.6
T4R1	5/27	B	DFM	N	6	15.00	20.00	20.00	0.4	51.8	51.6	3.45	3.44	99.6
T4R2	5/28	B	DFM	N	8	21.50	26.50	26.38	8.1	68.7	62.8	3.19	2.92	91.4
T4R5	5/29	S	DFM	N	11	22.97	26.00	24.74	7.6	67.4	59.3	2.93	2.58	87.9
T8	5/28	B	DFM	N	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
T3**	5/28	S	DFM	Y	11	10.15	15.00	13.00	17.0	38.8	27.9	3.82	2.75	71.9
T3R	5/28	B	DFM	Y	7	15.00	21.50	19.50	12.5	55.7	44.2	3.71	2.95	79.3
T3R1	5/29	S	DFM	Y	11	23.00	28.00	23.88	10.6	72.6	55.3	3.16	2.41	76.2
T3R2	5/29	S	DFM	Y	10	22.00	23.75	20.00	8.8	61.5	47.2	2.80	2.15	76.7
T5	5/29	S	DFM	N	11	23.00	24.75	24.50	7.3	64.1	58.9	2.79	2.56	91.8
T5R	5/30	S	JP5	N	11	23.00	26.00	26.00	2.8	67.4	65.5	2.93	2.85	97.2
T5R1	5/30	S	JP5	N	11	23.00	25.25	25.25	3.5	65.4	63.2	2.85	2.75	96.5
T5R2	5/30	S	JP5	N	11	23.00	21.25	21.25	2.8	55.0	53.5	2.39	2.33	97.3
T5R3	5/30	S	JP5	N	11	23.00	18.50	18.50	5.6	47.9	45.2	2.08	1.97	94.4

* Barrel 100F1 used first
** Compressor stalled

NA Data not available or necessary data to compute the item is not available
Pumps: B = Pump shipped with system, S = Replacement pump

TABLE C-3. OVERALL TEST RESULTS

Test No.	Date	Pump	Oil Used	Waves	Belt Speed (rpm)	Total Volume (gal)	Oil Volume (gal)	Fluid Rec. Rate (gpm)	Oil Rec. Rate (gpm)	Rec. Efficiency (%)
T4	5/27	B	DFM	N	11	158.2	122.4	3.52	2.72	77.4
T4R*	5/27	B	DFM	N	6	135.0	123.9	3.00	2.75	91.8
T4R1	5/27	B	DFM	N	6	105.2	91.3	3.51	3.04	86.8
T4R2	5/28	B	DFM	N	8	130.1	116.8	2.89	2.60	89.8
T4R5	5/29	S	DFM	N	11	127.4	105.6	2.83	2.35	83.0
T8	5/28	B	DFM	N	NA	49.0	42.8	NA	NA	87.3
T3**	5/28	S	DFM	Y	11	130.5	82.6	4.06	2.57	63.3
T3R	5/28	B	DFM	Y	7	90.8	64.7	3.03	2.16	71.2
T3R1	5/29	S	DFM	Y	11	140.6	101.4	3.12	2.25	72.1
T3R2	5/29	S	DFM	Y	10	125.9	93.8	2.80	2.09	74.5
T5	5/29	S	DFM	N	11	131.4	119.8	2.92	2.66	91.2
T5R	5/30	S	JP5	N	11	119.7	111.9	2.66	2.49	93.5
T5R1	5/30	S	JP5	N	11	128.3	119.2	2.85	2.65	92.9
T5R2	5/30	S	JP5	N	11	100.4	93.8	2.23	2.08	93.4
T5R3	5/30	S	JP5	N	11	97.6	90.0	2.17	2.00	91.2

* Barrel 100F1 used first

** Compressor stalled

NA Data not available or necessary data to compute the item is not available

TABLE C-4. COMPARISON OF STATISTICAL RESULTS FOR INTRA-TEST RESULTS

Statistical Results of Recovery Efficiency Results

Oil	Condition	Tests	RE Early (%)	RE Late (%)	RE Overall (%)
DFM	Calm	4	83 ± 12	93 ± 6	88 ± 6
DFM	Waves	4	65 ± 9	76 ± 5	70 ± 7
JP5	Calm	5	89 ± 1	95 ± 3	93 ± 2

Statistical Results of Oil Recovery Rate*

Oil	Condition	Tests	ORR Early (gpm)	ORR Late (gpm)	ORR Overall (gpm)
DFM	Calm	5	2.5 ± 0.5 (9.5 ± 1.9)	2.9 ± 0.6 (11.0 ± 2.3)	2.7 ± 0.4 (10.2 ± 1.5)
DFM	Waves	4	2.4 ± 1.0 (9.1 ± 3.8)	2.6 ± 0.5 (9.8 ± 1.9)	2.3 ± 0.3 (8.7 ± 1.1)
JP5	Calm	5	2.2 ± 0.5 (8.3 ± 1.9)	2.5 ± 0.4 (9.5 ± 1.5)	2.4 ± 0.4 (9.1 ± 1.5)

* OK Recovery Rate in liter per minute are shown in parentheses.

APPENDIX D

QA DATA & CALIBRATIONS

Validation of Shipping Scale

Thirty 20-lb weights were available as local standards. The shipping scale was validated using these weights. The steel cylinders were stacked on the scale as listed in Table D-1 and the weight registered by the scale was recorded.

Five aluminum blocks were selected and weighed. The individual blocks were weighed. The results are listed in Table D-2. The 20-lb weights were then used in combination with the aluminum blocks to obtain the remainder of the range of the scale. The measurements made at the extended end of the range is shown in Table D-3. The calibration results are shown in Figure D-1.

Recovery Barrel Calibrations

Recovery Barrels--

Two barrels were used to collect received fluids. Both barrels have a nominal capacity of 100 gallons (378 l). One barrel had a flat bottom; the second had a conical bottom. A volume of tap water was put into the barrel. The weight of the barrel and contents was then weighed and the height of water measured. The weight and height were recorded. The water was sampled and the specific gravity was determined. The weight of the water and the specific gravity were used to determine the volume of the contained liquid. As shown in Tables D-4 and D-5. The data were subjected to least squares regression to obtain the height-volume relationship as shown in Figures D-2 and D-3.

TABLE D-1. VALIDATION OF SHIPPING SCALE

No. of Weights	Applied Weight (lb)	Measured Weight (lb)
0	0	0
1	20	20.25
2	40	40.00
3	60	60.00
4	80	80.00
5	100	100.00
6	120	120.00
10	200	200.00
15	300	300.00
20	400	399.75
25	500	500.00
28	560	560.00
30	600	600.00

TABLE D-2. WEIGHTS OF ALUMINUM BLOCKS

Block Identification	Measured Weight (lb)
A	112
B	110
C	113
D	111
E	114
Sum	560

TABLE D-3. EXTENDED VALIDATION

Additional Weights*	Applied Weight (lb)	Measured Weight (lb)
0	560.25	560.25
2	600.25	600.25
7	700.25	700.00
12	800.25	800.25
17	900.25	900.00
22	1000.25	1000.00
27	1100.25	1100.00

* Number of 20-lb weights used in addition to all of the aluminum blocks (A through E). It is assumed that the aluminum blocks weigh exactly 560.25 lb.

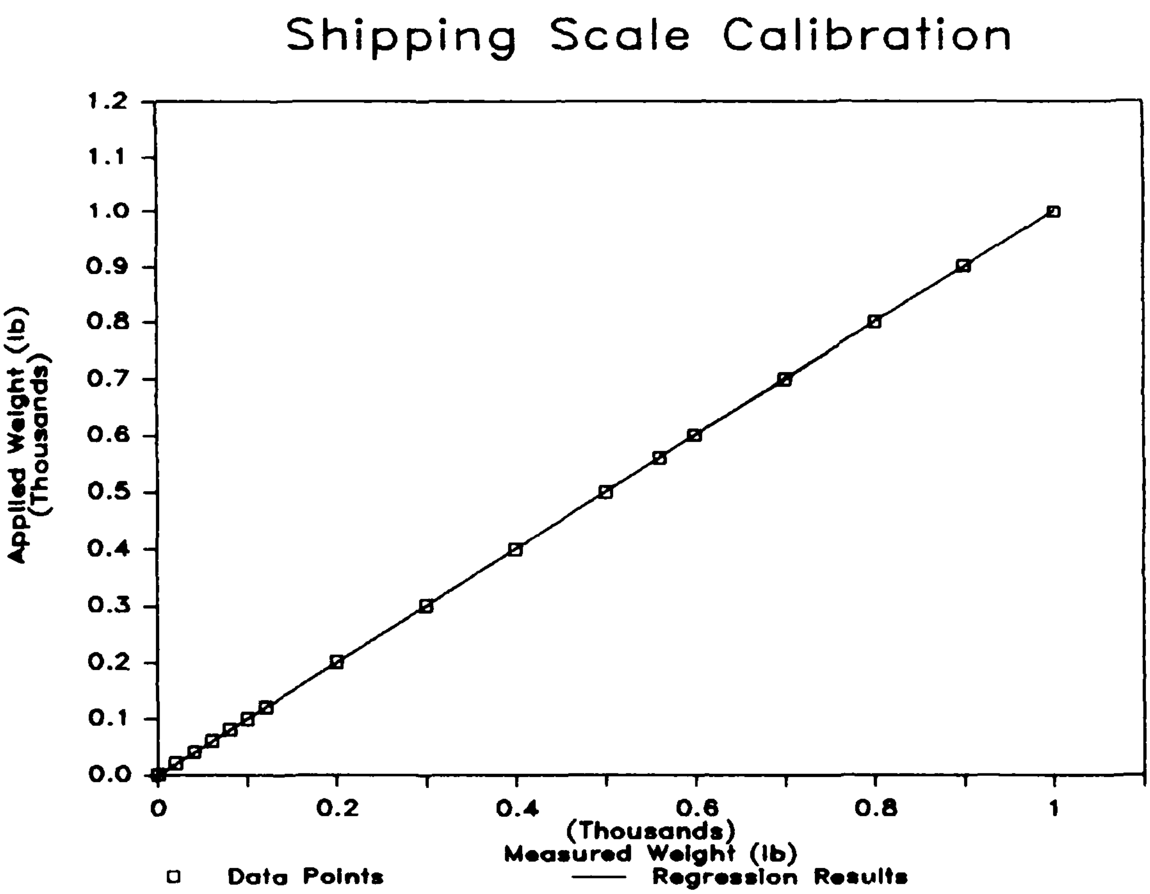


Figure D-1. The results of the shipping scale calibration are shown above along with the least squares regression line. The regression results were

$y = 1.0003x - 0.063$, $r = 1.0$, $Syx = 0.095$, $\overline{X} = 432$ lb

where y = applied weight and x = measured weight.

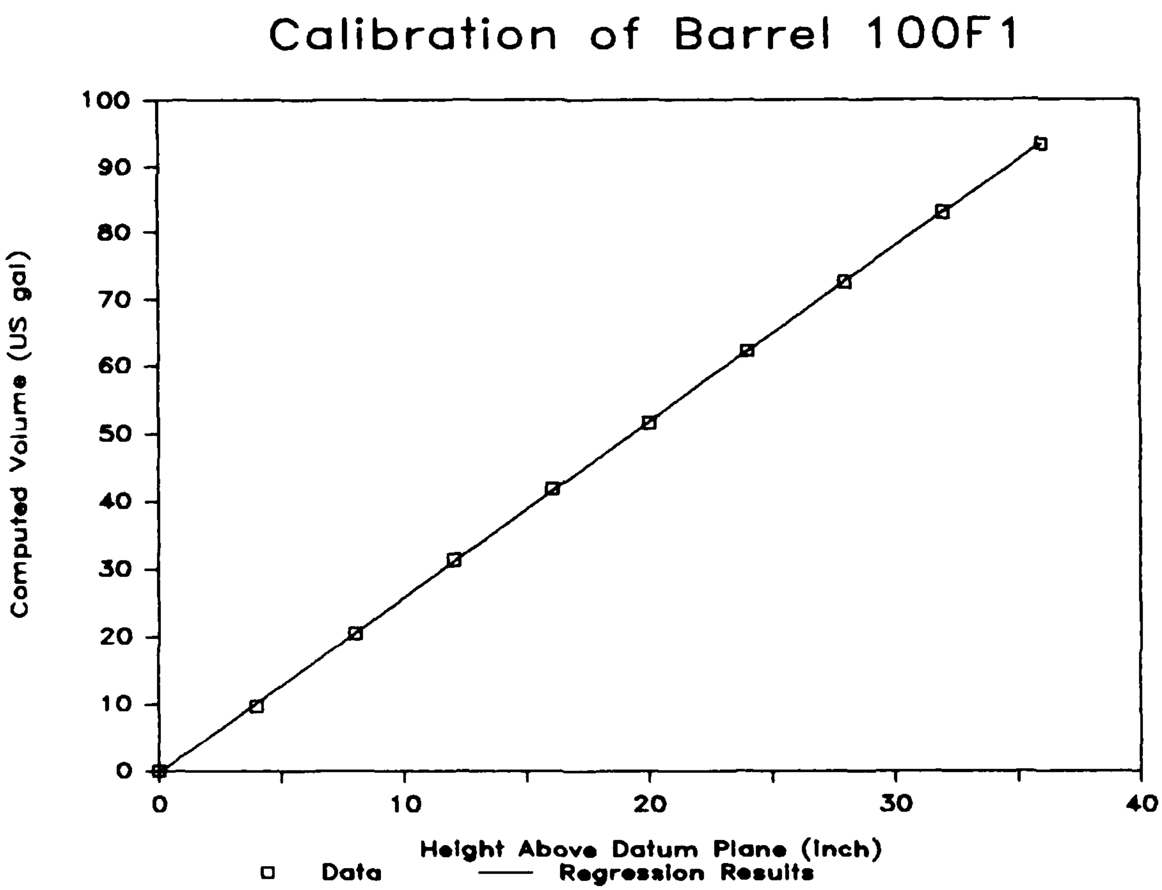


Figure D-2. The shipping scale was used to determine the volume-height relationship for the flat bottom barrel. The bottom of the barrel is the datum plane.

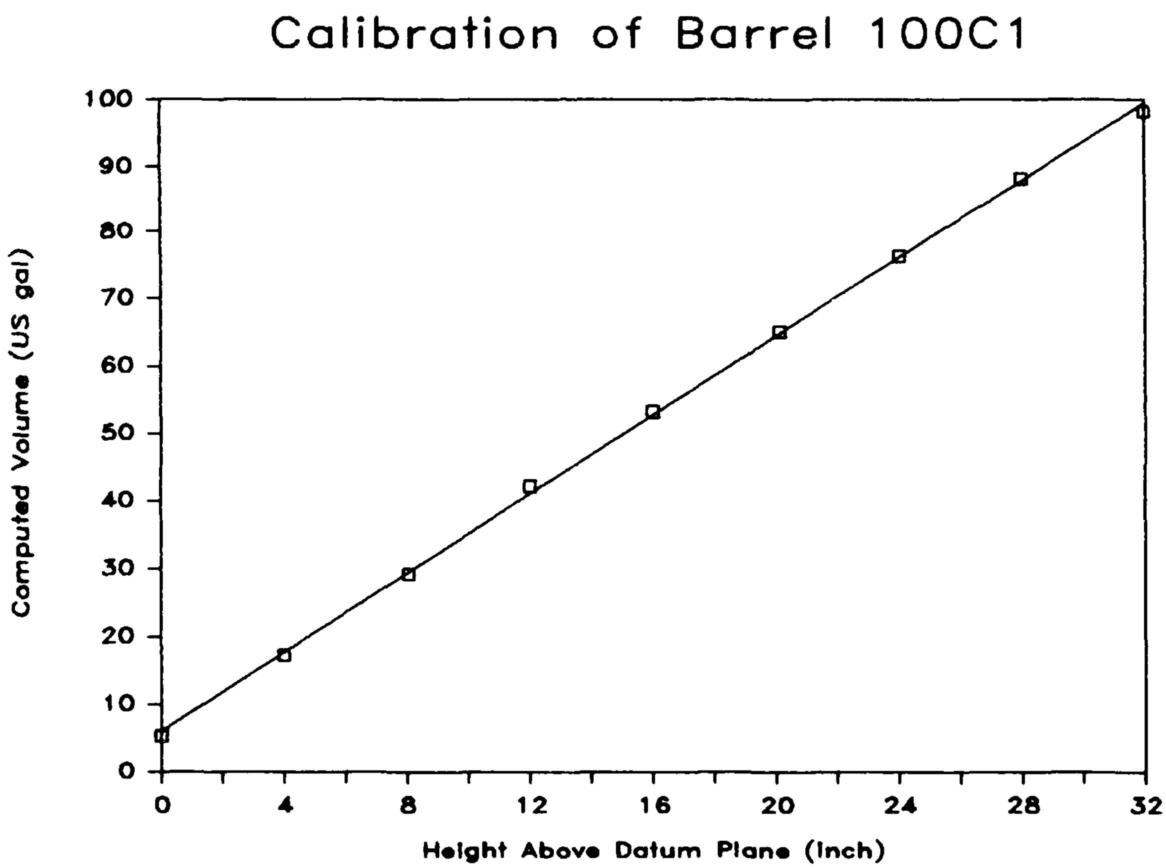


Figure D-3. The shipping scale was used to determine the volume-height relationship of the 100-gallon conical bottom barrel. The datum plane for this barrel was defined as the top of the cone. The volume of the cone is therefore the intercept in the regression line.

Barrel ID	100F1	100C1
Intercept	-0.21	5.95 gallon
Slope	2.60	2.92 gallon/inch
r^2	0.9999	0.9995

The coefficient of correlation in each case demonstrates that the barrels maintain uniform cross section as the liquid is added. These regression results were used to convert depth soundings to volumes in the calculation of oil recovery rates and recovery efficiencies.

Pump Test Barrels--

Two larger barrels were used in tests to determine the pump rate and bladder storage capacity. These barrels had a nominal capacity of 250 gallons (946 liter). The calibration of these barrels followed the same procedure as the 100-gallon barrels. The maximum capacity of the shipping scale, 1200 lb (545.5 Kg), prevented full calibration. Water was added through a depth of 15 inch (381 mm) to determine the tank constant, volume per unit depth. It is assumed from earlier calibrations that the barrels remain uniform in cross section and therefore have a constant volume per unit depth. The data collected was subjected to a least squares regression (see Table D-6 and D-7) to determine the constants.

TABLE D-4. 100 GALLON FLAT BARREL CALIBRATION DATA
(Barrel ID = 100F1)

Measured Height (inch)*1	Height (mm)*1	Measured Weight (lb) *2	Tared Weight (lb) *2	Tared Weight (kg) *3	Computed Volume (m^3)	Computed Volume (gal)	x^2	y^2	xy
0.0000	0.0	46.00	0.00	0.0	0.000	0.0	0.00	00.00	0.00
4.0000	101.6	126.50	80.50	36.6	0.037	9.7	16.00	93.81	38.74
8.0000	203.2	216.00	170.00	77.3	0.077	20.5	64.00	418.37	163.63
12.0625	306.4	306.00	260.00	118.2	0.118	31.3	145.50	978.62	377.35
16.0625	408.0	394.00	348.00	158.2	0.158	41.9	258.00	1753.18	672.55
20.0000	508.0	475.00	429.00	195.0	0.195	51.6	400.00	2664.29	1032.34
24.0000	609.6	546.50	518.50	235.7	0.236	62.4	576.00	3891.93	1497.25
28.0000	711.2	649.00	603.00	274.1	0.275	72.6	784.00	5263.83	2031.46
32.0000	812.8	735.00	689.00	313.2	0.314	82.9	1024.00	6872.35	2652.79
36.0000	914.4	821.00	775.00	352.3	0.353	93.2	1296.00	8695.02	3356.90

*1 Height measured with meterstick. Error estimated constant ± 1/16 inch (1.6 mm) over length of scale (1.6 mm). Height measured top of cone at datum plane.

*2 Weight measured with shipping scale. Error estimated as 0.25 lb.

*3 Tare weight 46 lb. Tare includes empty barrel only. Weights taken with water temperature 63.5 ± 0.2°F.

*4 Calculated volume based on density 998 Kg/m^3.
V (m^3)=wt (Kg) / (998 Kg/m^3)
estimated error from calculations 1%
V (gal)=V (m^3)*(264.172 gal/m^3)
998 Kg/m^3 based on Specific Gravity Measurement of 0.998 ± 0.005 at 26.3 ± 0.1C

TABLE D-5. 100 GALLON FLAT BARREL CALIBRATION DATA
(Barrel ID = 100C1)

Measured Height (inch)*1	Height (mm)*1	Measured Weight (lb) *2	Tared Weight (lb) *2	Tared Weight (kg) *3	Computed Volume (m^3)	Computed Volume (gal)	x^2	y^2	xy
0.00	0	205.0	44.5	20.2	0.020	5.4	0.00	28.67	0.00
4.00	102	303.5	143.0	65.0	0.065	17.2	16.00	296.03	68.82
8.06	205	403.5	243.0	110.5	0.111	29.2	65.00	854.83	235.73
12.00	305	511.0	350.5	159.3	0.160	42.2	144.00	1778.46	506.06
16.00	406	603.0	442.5	201.1	0.202	53.2	256.00	2834.61	851.86
20.13	511	701.0	540.5	245.7	0.246	65.0	405.02	4229.20	1308.78
24.00	610	794.5	634.0	288.2	0.289	76.3	576.00	5818.96	1830.77
28.00	711	893.0	732.5	333.0	0.334	88.1	784.00	7767.52	2467.74
32.00	813	977.5	817.0	371.4	0.372	98.3	1024.00	9662.98	3145.62

*1 Height measured with meterstick. Error estimated constant ± 1/16 inch over length of scale (1.6 mm). Height measured from top of cone at datum plane.

*2 Weight measured with shipping scale. Error estimated at 0.25%

*3 Tare weight 160.5 lb. Tare included (1) barrel, (2) angle iron stand, and (3) shims. Weight of shims 1 lb, weight of barrel 159.5 lb. Weights taken at 17.5C ± 0.1.

*4 Calculated volume based on 1000 Kg/m^3
$V (m^3) = wt (kg)/(998 Kg/m^3)$
Estimated error from calculations 1%
$V (gal) = V (m^3)*(264.172 gal/m^3)$
1000 Kg/m^3 based on Specific Gravity Measurement of 0.998 ± 0.005
at 26.3 ± 0.1 C

TABLE D-6. CALIBRATION DATA 250 GALLON CONICAL BOTTOM BARREL 250C1

Measured Height (inch)*1 (x)	Height (mm)*1	Measured Weight (lb) *2	Tared Weight (lb) *2	Tared Weight (kg) *3	Computed Volume (m^3)	Computed Volume (gal) (y)	x^2	y^2	xy	y^2
0	0	406.50	0.00	0.000	0.00	0.00	0.00	0.000	0.000	0.95
1	25	465.25	58.75	26.705	0.03	7.07	1.00	49.966	7.069	7.04
2	51	517.25	110.75	23.636	0.05	13.33	4.00	177.561	26.650	13.13
3	76	568.75	162.25	23.409	0.07	19.52	9.00	381.092	58.565	19.22
4	102	617.50	211.00	22.159	0.10	25.39	16.00	644.504	101.548	25.31
5	127	663.50	257.00	20.909	0.12	30.92	25.00	956.152	154.609	31.40
6	152	723.75	317.25	27.386	0.14	38.17	36.00	1457.014	229.025	37.49
7	178	771.75	365.25	21.818	0.17	43.95	49.00	1931.261	307.623	43.58
8	203	820.75	414.25	22.273	0.19	49.84	64.00	2484.194	398.734	49.67
9	229	872.50	466.00	23.523	0.21	56.07	81.00	3143.637	504.613	55.76
10	254	920.50	514.00	21.818	0.23	61.84	100.00	3824.607	618.434	61.86
11	279	971.50	565.00	23.182	0.26	67.98	121.00	4621.229	747.776	67.95
12	305	1021.75	615.25	22.841	0.28	74.03	144.00	5479.788	888.307	74.04
13	330	1072.50	666.00	23.068	0.30	80.13	169.00	6421.094	1041.712	80.13
14	356	1120.25	713.75	21.705	0.33	85.88	196.00	7374.843	1202.277	86.22
15	381	1170.75	764.25	22.955	0.35	91.95	225.00	8455.347	1379.294	92.31

N = 16
B = 6.090519 gal/in
A = 0.949936 gal
r^2 = 0.999911
Syx = 0.398385
X bar = 7.5 in

TABLE [illegible]. CALIBRATION DATA 250 GALLON CONICAL [illegible] BARREL 250C2

Measured Height (inch)*1 (x)	Height (mm)*1	Measured Weight (lb) *2	Tared Weight (lb) *2	Tared Weight (kg) *3	Computed Volume (m^3)	Computed Volume (gal) (y)	x^2	y^2	xy	y^2
0	0	431.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
1	25	485.50	54.25	24.66	0.02	6.59	1.00	43.39	6.59	6.04
2	51	526.75	95.50	43.41	0.24	11.60	4.00	134.47	23.19	11.90
3	76	577.00	145.75	66.25	0.07	17.70	9.00	313.22	53.09	17.75
4	102	625.00	193.75	88.07	0.09	23.53	16.00	553.49	94.11	23.60
5	127	671.50	240.25	109.20	0.11	29.17	25.00	851.05	145.86	29.46
6	152	722.00	290.75	132.16	0.13	35.30	36.00	1246.43	211.83	35.31
7	178	769.00	337.75	153.52	0.16	41.01	49.00	1681.97	287.08	41.16
8	203	822.50	391.25	177.84	0.18	47.51	64.00	2257.03	380.07	47.01
9	229	868.75	437.50	198.86	0.20	53.12	81.00	2822.17	478.12	52.87
10	254	915.50	484.25	220.11	0.22	58.80	100.00	3457.54	588.01	58.72
11	279	963.00	531.75	241.70	0.24	64.57	121.00	4169.10	710.25	64.57
12	305	1010.50	579.25	263.30	0.27	70.34	144.00	4947.20	844.04	70.42
13	330	1058.50	627.25	285.11	0.29	76.16	169.00	5801.08	990.14	76.28
14	256	1106.00	674.75	306.70	0.31	81.93	196.00	6712.95	1147.06	82.13
15	381	1156.50	725.25	329.66	0.33	88.06	225.00	7755.38	1320.97	87.98

N = 16
B = 5.852717 gal/inch
A = 0.191961 gal
R^2 = 0.999960
Syx = 0.255871

TABLE D-8. CALIBRATION OF SHIPPING SCALE

Number of Weights	y Applied Weight (lb)	x Measured Weight (lb)	x^2	y^2	xy	y'
0	0	0.00	0	0	0	0.06
1	20	20.25	410	400	405	20.19
2	40	40.00	1600	1600	1600	39.95
3	60	60.00	3600	3600	3600	59.95
4	80	80.00	6400	6400	6400	79.96
5	100	100.00	10000	10000	10000	99.97
6	120	120.00	14400	14400	14400	119.97
10	200	200.00	40000	40000	40000	200.00
15	300	300.00	90000	90000	90000	300.02
20	400	399.75	159800	160000	159900	399.80
25	500	500.00	250000	250000	250000	500.08
28	560	560.00	313600	313600	313600	560.10
30	600	600.00	360000	360000	360000	600.11
0	560.25	560.25	313880	313880	313880	560.35
2	600.25	600.25	360300	360300	360300	600.36
7	700.25	700.00	490000	490350	490175	700.14
12	800.25	800.00	640000	640400	640200	800.17
17	900.25	900.00	810000	810450	810225	900.20
22	1000.25	1000.00	1000000	1000500	1000250	1000.23
27	1100.25	1100.00	1210000	1210500	1210275	1100.26
Total		8641.75	8640.5	6073990	6076430	6075210

N = 20
A = 0.065295 lb measured
B = 1.000290 lb measured/lb applied
R^2 = 0.999999
Syx = 0.094853

APPENDIX E

LABORATORY ANALYSES

PHYSICAL PROPERTIES OF TEST OILS

The physical properties of the test oils was determined prior to dying the oil and after the dye addition. The dye was added after the second test. The dye was added to make the observation of the oil more distinct. The dye addition did not alter the physical properties of the test oils within measurable limits.

The viscosity measurements of the oil prior to dying are given in Table E-1. These were made using a Brookfield Viscometer (Model LVT). The other physical measurements are listed in Table E-2 (the physical properties of the dyed test oil are listed in Tables E-3 and E-4). Bottom solids and water are measured using method outlined in ASTM 1796. Specific gravity was measured using a calibrated hydrometer following the specifications found in ASTMD 1298. The flashpoints listed are the closed cup flashpoints. These were determined using a Fisher/Tag closed cup tester and procedures outlined in ASTM D-56. Surface and interfacial tensions were measured using Fisher Surface Tensiomet and procedures outlined in ASTM D-971.

WATER CONTENT

The relative water content in the stratified samples were analyzed with ASTM 1796 with the variation noted in the test. The values determined by this method are listed in Table E-5.

TABLE E-1. VISCOSITY MEASUREMENTS OF THE TEST OILS PRIOR TO DYEING *1

Temperature (C)	DFM Viscosity (cSt)	JP5 Viscosity (cSt)
26	4.3	5.4
37	4.4	5.6
50	3.8	4.9

*1 Physical properties reported as OHMSETT lab report 969.

TABLE E-2. OTHER PHYSICAL PROPERTIES OF THE TEST OILS PRIOR TO DYEING *1

	JP5	DFM
Bottom Solids and Water	0.01 v/o	0.01 v/o
Specific Gravity @ 26C	0.812	0.840
Specific Gravity @ 37C	0.805	0.833
Flashpoint	137F (58C)	168F (76C)
Surface Tension @ 26C	28.2 dyne/cm	30.9 dyne/cm
Interfacial Tension @ 26 C over Tank Water	19.8 dyne/cm	21.7 dyne/cm

*1 Physical properties reported as OHMSETT lab report 969.

TABLE E-3. VISCOSITY MEASUREMENTS OF THE TEST OILS AFTER DYEING *1

DFM Temperature (C)	DFM Viscosity (cSt)	JP5 Viscosity (cSt)
20	-	4.0
36	-	4.0
36	-	4.0
23	6.6	-
37	6.2	-

TABLE E-4. OTHER PHYSICAL PROPERTIES OF THE TEST OILS AFTER DYEING *1

	JP5	DFM
Bottom Solids and Water	0.01	0.01 v/o
Specific Gravity @ 20C	-	0.813
Specific Gravity @ 36C	-	0.807
Specific Gravity @ 23C	0.839	-
Specific Gravity @ 37C	0.831	-
Surface Tension	29	29
Interfacial Tension @ 26 C over Tank Water	23	22

*1 Physical properties reported as OHMSETT lab reports 972, 975

TABLE E-5. SUMMARY OF WATER CONTENT DETERMINATIONS

Test No. & Barrel ID	Sample No.	Sample Volume (ml)	Water Volume (ml)	Relative Water Content (%)	Average*1 Water Content (%)
T3C	1	93 ±2	15.06 ±1.02	16.19 ±1.4	
T3C	2	92 ±2	9.01 ±0.32	9.79 ±0.6	12.99 ±1.45
T3F	1	42 ±1	6.8 ±0.3	16.19 ±1.1	
T3F	2	45 ±1	8 ±0.3	17.78 ±1.1	16.98 ±1.10
T3R1C	1	69 ±2	0 ±0.04	0.00 ±0.1	
T3R1C	2	69 ±2	0.2 ±0.04	0.29 ±0.1	0.14 ±0.07
T3R1F	1	81 ±2	8 ±0.32	9.88 ±0.6	
T3R1F	2	81 ±2	9.1 ±0.32	11.23 ±0.7	10.56 ±0.67
T3R2C	1	74 ±2	0.5 ±0.04	0.68 ±0.1	
T3R2C	2	74 ±2	0.2 ±0.04	0.27 ±0.1	0.47 ±0.07
T3R2F	1	66 ±2	6 ±0.32	9.09 ±0.8	
T3R2F	2	70 ±2	6 ±0.32	8.57 ±0.7	8.83 ±0.76
T3RC	1	42 ±1	7 ±0.3	16.67 ±1.1	
T3RC	2	43 ±1	6 ±0.3	13.95 ±1.0	15.31 ±1.11
T3RF	1	66 ±2	8 ±0.32	12.12 ±0.9	
T3RF	2	63 ±2	8.1 ±0.32	12.86 ±0.9	12.49 ±0.92
T4C	1	93 ±2	0.2 ±0.04	0.22 ±0.0*	
T4C	2	100 ±2	15.5 ±1.02	15.50 ±1.3	
T4C	3	97 ±2	16.1 ±1.2	16.60 ±1.6	16.05 ±1.58
T4F	1	94 ±2	10 ±0.32	10.64 ±0.6	
T4F	2	94 ±2	8.4 ±0.32	8.94 ±0.5	
T4F	3	100 ±2	8.3 ±8.30	8.30 ±0.5	9.29 ±0.57
T4R1C	1	75 ±2	14.07 ±1.02	18.76 ±1.9	
T4R1C	2	70 ±2	15.02 ±1.02	21.46 ±2.1	
T4R1C	3	76 ±2	0.02 ±0.04	0.03 ±0.1*	20.11 ±2.07
T4R1F	1	70 ±2	0.4 ±0.04	0.57 ±0.1	
T4R1F	2	69 ±2	0.16 ±0.04	0.23 ±0.1	
T4R1F	3	75 ±2	0.34 ±0.04	0.45 ±0.1	0.42 ±0.07

Continued

TABLE E-5. (CONTINUED)

Test No. & Barrel ID	Sample No.	Sample Volume (ml)	Water Volume (ml)	Relative Water Content (%)	Average*1 Water Content (%)
T4R2C	1	71 ±2	0.2 ±0.04	0.28 ±0.1	
T4R2C	2	71 ±2	0.16 ±0.04	0.23 ±0.1	
T4R2C	3	70 ±2	0.12 ±0.04	0.17 ±0.1	0.23 ±0.06
T4R2F	1	92 ±2	9.01 ±0.32	9.79 ±0.6	
T4R2F	2	91 ±2	8.03 ±0.32	8.82 ±0.5	
T4R2F	3	87 ±2	5.02 ±0.32	5.77 ±0.5	8.13 ±0.56
T4R5C	1	72 ±2	0.1 ±0.04	0.14 ±0.1	
T4R5C	2	72 ±2	0.1 ±0.04	0.14 ±0.1	
T4R5C	3	73 ±2	0.2 ±0.04	0.27 ±0.1	0.18 ±0.06
T4R5F	1	85 ±2	7 ±0.32	8.24 ±0.6	
T4R5F	2	83 ±2	7 ±0.32	8.43 ±0.6	
T4R5F	3	83 ±2	5 ±0.22	6.02 ±0.4	7.56 ±0.59
T4RC	1	85 ±2	1.65 ±0.04	1.94 ±0.1	
T4RC	2	84 ±2	1.61 ±0.04	1.92 ±0.1	
T4RC	3	88 ±2	1.41 ±0.04	1.60 ±0.1	1.82 ±0.09
T4RF	1	85 ±2	7.5 ±0.32	8.82 ±0.6	
T4RF	2	84 ±2	7 ±0.32	8.33 ±0.6	
T4RF	3	81 ±2	6.6 ±0.32	8.15 ±0.6	8.44 ±0.60
T5C	1	85 ±2	0 ±0.04	0.00 ±.0	
T5C	2	86 ±2	0 ±0.04	0.00 ±.0	
T5C	3	88 ±2	0.4 ±0.04	0.45 ±0.1	0.15 ±0.06
T5F	1	81 ±2	6 ±0.32	7.41 ±0.6	
T5F	2	79 ±2	5.5 ±0.32	6.96 ±0.6	
T5F	3	80 ±2	6 ±0.32	7.50 ±0.6	7.29 ±0.59
T5R1C	1	86 ±2	0 ±0.04	0.00 ±.0	
T5R1C	2	80 ±2	3 ±0.04	3.75 ±0.1	
T5R1C	3	82 ±2	3 ±0.04	3.66 ±0.1	2.47 ±0.14
T5R1F	1	80 ±2	0.7 ±0.04	0.88 ±0.1*	
T5R1F	2	83 ±2	2.7 ±0.04	3.25 ±0.1	
T5R1F	3	82 ±2	3 ±0.04	3.66 ±0.1	3.46 ±0.14

Continued

TABLE E-5. (CONTINUED)

Test No. & Barrel ID	Sample No.	Sample Volume (ml)	Water Volume (ml)	Relative Water Content (%)	Average*1 Water Content (%)
T5R2C	1	59 ±2	0 ±0.04	0.00 ±0.1	
T5R2C	2	59 ±2	0 ±0.04	0.00 ±0.1	
T5R2C	3	64 ±2	0 ±0.04	0.00 ±0.1	0.00 ±0.07
T5R2F	1	67 ±2	2 ±0.04	2.99 ±0.1	
T5R2F	2	65 ±2	1.7 ±0.04	2.62 ±0.1	
T5R2F	3	68 ±2	1.8 ±0.04	2.65 ±0.1	2.75 ±0.15
T5R3C	1	65 ±2	1.3 ±0.04	2.00 ±0.1	
T5R3C	2	64 ±2	1.3 ±0.04	2.03 ±0.1	
T5R3C	3	70 ±2	1.3 ±0.04	1.86 ±0.1	1.96 ±0.13
T5R3F	1	59 ±2	3 ±0.04	5.08 ±0.2	
T5R3F	2	59 ±2	3.5 ±0.04	5.93 ±0.3	
T5R3F	3	60 ±2	3.5 ±0.04	5.83 ±0.3	5.62 ±0.27
T5RC	1	71 ±2	0.2 ±0.04	0.28 ±0.1	
T5RC	2	70 ±2	0 ±0.04	0.00 ±0.1	
T5RC	3	70 ±2	0 ±0.04	0.00 ±0.1	0.09 ±0.06
T5RF	1	73 ±2	3.5 ±0.22	4.79 ±0.4	
T5RF	2	82 ±2	1.2 ±0.04	1.46 ±0.1	
T5RF	3	81 ±2	1.7 ±0.04	2.10 ±0.1	2.79 ±0.43
T8C	1	74 ±2	6.51 ±0.32	8.80 ±0.7	
T8C	2	75 ±2	8 ±0.32	10.67 ±0.7	
T8C	3	72 ±2	3 ±0.22	4.17 ±0.4	7.88 ±0.71
T4C	1	93 ±2	0.2 ±0.04	0.22 ±.0*	
T4C	2	100 ±2	15.5 ±1.02	15.50 ±1.3	
T4C	3	97 ±2	16.6 ±1.2	17.11 ±1.6	16.31 ±1.59
T4F	1	94 ±2	10.4 ±0.32	11.06 ±0.6	
T4F	2	103 ±3	7.8 ±0.32	7.57 ±0.5	
T4F	3	81 ±2	6.6 ±0.32	8.15 ±0.6	8.93 ±0.60

* Data point labeled as outlier.
**1 Error given as maximum of values in set

END

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